PB-216 567

RADIOACTIVE WASTE PROBLEMS IN THE NORTHWEST

Edward F. Eldridge

Public Health Service
Portland, Oregon

November 1960

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PB 216 567

PROCEEDINGS

of the

EIGHTH SYMPOSIUM

on

WATER POLLUTION RESEARCH

RADIOACTIVE WASTE PROBLEMS

IN THE NORTHWEST

Assembled by

Edward F. Eldridge

Technical & Research Consultation Project

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U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE

Public Health Service

Region IX

Portland, Oregon

November, 1960

FOREWORD

In May 1957 the Public Health Service initiated the "Technical and Research Consultation Project" as a means of better reaching and serving those engaged in water pollution research in the Northwest. A series of symposiums have been held as one of the activities of this Project. The purpose of these symposiums is to provide an opportunity for a free and informal exchange of knowledge on subjects related to water pollution. The following is a list of the subjects covered by the seven symposiums held to date:

1. Research Relating to Problems of Water Pollution in the Northwest
2. Financing Water Pollution Research
3. The Slime (Sphaerotilus) Problem
4. Short-term Bio-Assay
5. Siltation - Its Sources and Effects on the Aquatic Environment
6. Oceanography and Related Estuarial Water Problems of the Northwest
7. Status of Knowledge of Water Problems of the Northwest
8. Radioactive Waste Problems in the Pacific Northwest

These proceedings are compiled from the prepared papers and discussions of the Eighth Symposium held in Portland, Oregon on November 15, 1960. The agenda has six major parts, each with one or more persons with special knowledge and experience in the specific subject discussed. Each of these persons presented prepared statements which are included. The discussions were recorded and are abstracted in these proceedings.

EIGHTH SYMPOSIUM ON WATER POLLUTION RESEARCH IN THE NORTHWEST

SUBJECT: RADIOACTIVE WASTE PROBLEMS OF THE NORTHWEST

TIME AND PLACE: Tuesday, November 15, 1960, Rm. 104, U.S. Court House Building, Portland, Oregon

AGENDA:

9:00 A.M. Introductory Remarks - E. F. Eldridge, Physical Sciences Administrator

9:05 - 10:00 A. RADIOLOGY
General Fundamentals and Instrumentation. Prepared remarks by Dr. Arthur Scott, Department of Chemistry, Reed College and Dr. John Thorpe, Assoc. Pathologist and Director of Isotopes Laboratory, Good Samaritan Hospital, Portland, Oregon.

10:00 - 10:45 B. SOURCES AND LEVELS OF RADIOACTIVITY
Prepared remarks by Dr. Ernest Tsivogolou Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

10:45 - 12:00 C. RADIOACTIVITY AS A POLLUTION PROBLEM
Methods of Waste Disposal: Prepared remarks by R. L. Junkins, General Electric Co., Hanford, Washington
Biological Considerations: Prepared remarks by Dr. Richard Foster, General Electric Co., Hanford, Wash.

1:00 - 2:00 D. PROBLEMS OF THE ADMINISTRATOR
Prepared remarks by Robert Stockman, Washington Department of Health, Seattle, Washington.
Prepared remarks by Curtiss Everts and Jack Weatherabee Oregon Department of Health, Portland, Oregon.

2:00 - 2:45 E. FUTURE USE OF ATOMIC ENERGY - Project CHARIOT, Alaska. Prepared remarks by Dr. Allyn H. Seymour, Deputy Director, Committee Environmental Program Project CHARIOT, University of Washington, Seattle, Washington.

2:45 - 4:30 F. USES OF ISOTOPES IN WATER RESEARCH
As Tracers: Prepared remarks by Dr. Warren Kaufman, Engineering Department, University of California, Berkeley, California.
For Flow Measurement: Prepared remarks by Dr. Bernard A. Fries, California Research Corporation, Richmond, California.

PROCEEDINGS OF THE EIGHTH SYMPOSIUM
ON
RADIOACTIVE WASTE PROBLEMS OF THE NORTHWEST

November 15, 1960

Assembled by

E. F. Eldridge *

Introductory Remarks - E. F. Eldridge

This is the eighth of a series of symposiums which have been held in this area on subjects related to water pollution. Today we are discussing certain phases of the problem of radioactive wastes.

We hope through these discussions to delineate present-day and anticipated future problems of radiation in waters of the Northwest and to mark out areas of needed research to meet these problems.

This is one of the most important and timely subjects we have discussed. Progress in the use of atomic energy both for defense and peace time purposes is so rapid that we have little time to waste in our consideration of the problems of waste disposal. We may not find any definite answers through our discussions today, but I am sure we will all leave with new ideas and interests.

Because of the nature of this subject it seems desirable to first discuss some of the general fundamentals of radioactivity and the units and instruments used in its measurement. A glossary has been prepared in order that we all will have the same understanding of terms used.

* Physical Sciences Administrator, Department of Health, Education and Welfare, Public Health Service, Water Supply and Water Pollution Control Program, Pacific Northwest, Portland, Oregon.

GENERAL FUNDAMENTALS AND INSTRUMENTATION

Arthur Scott*

According to accepted theory atoms consist of a nucleus surrounded by a cloud of electrons. Our discussion today will be concerned primarily with the nature and properties of the nuclei of atoms; and, when we shall want to emphasize this, we shall use the term "nuclide" rather than "atom."

Nuclei of atoms are composed of combinations of two particles which are generally referred to as "nucleons": the proton and the neutron. The proton is the nucleus of the hydrogen atom; it has a single (+) electrical charge and a weight of approximately unity on the ordinary scale of atomic weights. The neutron carries no electrical charge and, like the proton, has a weight of approximately unity. The number of nucleons making up the nucleus of an atom is called the "nucleon number" or "mass number" of the atom and represents the approximate weight of the atom on the atomic weight scale. The nucleon number is usually used to identify different isotopes of the same element: e.g., U-235 and U-238. In passing it may be noted that the nucleus of an atom carries a positive charge numerically equal to the number of protons present, which is referred to as the atomic number of the atom. The atomic number of an atom determines the chemical properties of that atom; because it determines the number of (-) charged electrons in the cloud surrounding the nucleus of the atom and these electrons, in turn, establish the chemical behavior of an atom. For example, to be precise in describing the two isotopes of uranium we could write $_{92}U^{235}$ and $_{92}U^{238}$ where 92 is the atomic number of uranium. For most purposes, however, the atomic number is superfluous since the symbol of the element indicates clearly the chemical properties of the atom.

Nuclides fall into two classes: stable and unstable. In the case of an unstable or radioactive nuclide the nucleus undergoes a spontaneous transformation to form a new and different nucleus, which may or may not be stable. The transformation

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*Dr. Arthur Scott, Professor of Chemistry, Reed College Portland, Oregon.

process is generally described as the radioactive decay or disintegration of the nucleus. Some radioactive nuclides are found in nature. Radioactive nuclides of most elements can be prepared by nuclear reactions which will be mentioned later. The fission of U-235 also results in the formation of radioactive nuclides as will be described later.

The radioactivity of a given sample of a radionuclide is specified in terms of the number of disintegrations taking place per second of time. The unit of radioactivity (or activity) is the "curie," (abbreviated:c) defined as 3.7×10^{10} (37 billion) disintegrations per second. Smaller units of activity which are convenient for certain purposes are

$$\text{millicurie (mc)} = \frac{1}{1000} \text{ curie}$$

$$\text{microcurie (}\mu\text{c)} = \frac{1}{1{,}000{,}000} \text{ curie}$$

The activity of any radionuclide is proportional to the number of unstable atoms present. For example, a 10 mc sample of I-131 contains 10 times as many unstable I-131 atoms as does a 1 mc sample.

Radioactive disintegration of an unstable nuclide is characterized by two things: (1) the rate at which the decay takes place; and (2) the nature of the radiations emitted by the disintegrating nucleus. These features of the disintegration process will be discussed briefly.

The rate of decay of a radionuclide is generally expressed in terms of its half-life (T), i.e., the length of time required for the disintegration of one-half of the radioactive atoms present in a given sample of the radionuclide. For example, since the half-life of I-131 is 8 days, one half of the I-131 atoms present in any given sample of I-131 will disintegrate and disappear in 8.0 days. Or to put it in a different way: if we start out with a 10 mc sample of I-131 we shall have 5 mc after 8 days, 2.5 mc after 16 days, 1.25 mc after 24 days, and so on. Half-lives of radionuclides vary over a very wide range: some half-lives are as short as microseconds and some are known to be of the order of billions of years.

In the process of disintegration an unstable nucleus emits or ejects a particle with considerable kinetic energy, which may or may not be accompanied by radiation similar to hard (penetrating) x-rays. The particles emitted are one of two kinds, alpha or beta

which will be identified more fully below - the x-ray like radiation emitted by a disintegrating nucleus is called gamma radiation.

The alpha and beta types of radiation can be described briefly in general terms.

Alpha. An alpha particle is the nucleus of a helium atom and can be represented by $_2He^4$. When it is ejected by an "alpha emitter", the atomic number and nucleon number are less than those characteristic numbers of the emitting nucleus by 2 and 4, respectively. For example:

$$Ra^{226} \xrightarrow[T=1600\ y]{\alpha} \quad Rn^{222} \xrightarrow[T=3.18\ d]{\alpha} \quad Po^{218}$$

In this example the product or daughter nuclide is also unstable and we have a radioactive chain. It should be noted that alpha particles from a given radionuclide all have the same energy.

Beta This term applies to two different kinds of high energy elections: negatrons (β^-) which are ordinary elections with a (-) charge; and positrons which are elections with a (+) charge. The emission of a beta particle by a nucleus does not change the nucleon number of the nucleus; it does, however, cause the atomic number of the nucleus to change. When a β^- is emitted the atomic number is increased by one and when a β^+ is emitted the atomic number is decreased by one. For example,

$$P^{32} \xrightarrow[T=14\ d]{\beta^-} S^{32}$$

$$Na^{22} \xrightarrow[2.6y]{\beta^+} Ne$$

It should be noted here that the beta particles from a given radionuclide cover a range of energies. The maximum energy, however, is characteristic of a radionuclide.

Since we are going to be concerned primarily with the effects of the radiations from radioactive nuclides, we shall consider them

in more detail, touching on the following topics: their detection; the energy of the radiations; their range or penetrating ability; and the energy which the different radiations deposit in samples of material which are exposed to them.

In discussions of nuclear phenomena it has become customary to consider energy changes relating to a single, individual atom or nucleus; and this has led to the use of a small unit of energy, the electron volt (ev). It will suffice here to say that chemical reactions when reduced to individual atoms or molecules involve energy changes of less than 5 ev, whereas nuclear reactions on the same basis involve millions of electron volts. For convenience, in connection with nuclear reactions, one makes use of the energy unit "mev" which is equal to 1,000,000 ev. Unless otherwise specified the mev unit is used in specifying the energy of radiations from radionuclide. Illustrations of this usage will be cited below. It should be noted that the energy of alpha and beta particles refer to their kinetic energies. Gamma radiation, however, appears to act like a bundle or atom of energy and this unit is termed a photon; and the energy reported for gamma radiation refers to the energy of its photon.

Alpha, beta, and gamma radiation in passing through matter can ionize the atoms of which the matter is composed; that is to say, an election outside the nucleaus is knocked out of the atom leaving what chemists call an ion. The ion and electron produced in this way are generally referred to as an "ion pair." In the case of air molecules about 35 ev of energy are required to produce an ion-pair. All the common means of detecting nuclear radiation depend ultimately on the ionizing effect of this radiation.

The harmful consequences of nuclear radiations to living organisms are generally supposed to result from chemical effects caused by the ion-pairs produced by the radiation in question. It is assumed therefore that in any given case the extent of biological damage resulting from exposure to radiation will be related directly to the amount ionization caused by the radiation, that is, to the amount of radiation energy deposited in the biological sample. The most general unit of radiation absorption is the "rad" which is defined as "the absorbed dose of any nuclear radiation which is accompanied by the liberation of 100 ergs of energy per gram of absorbing material." For practical purposes in the case of soft tissue, the rad is equivalent to the older units: roentgen and rep.

Although all radiation from radioactive decay is ionizing the mechanism whereby the radiation produces ion-pairs is not the same for gamma radiation and particulate radiation (alpha and beta) and

it will therefore be simplest to treat these two kinds of radiation separately.

Gamma radiation. A beam of gamma radiation can be pictured as a stream of high energy photons. In passing through, say, 1 cm of material a certain small fraction of the photons will be absorbed and converted into ion-pairs. This attenuation of the gamma beam depends on the nature of the material. In the case of air the attenuation is extremely small (about 0.005%), an amount which is negligible for many purposes. (See discussion of "inverse square law" below). Nevertheless, the ion pairs produced even by this small absorption provide a convenient means of measuring the intensity of gamma radiation and we find therefore the unit of gamma radiation defined in this way. The roentgen unit is defined as that amount of x- or gamma radiation which will produce 2.1 billion ion pairs in 1 cc of dry air under standard conditions. Instruments to measure the intensity of gamma radiation express this intensity as roentgens/hour or milliroentgens/hour. As mentioned above the energy absorption in tissue for one roentgen of of fairly high energy photons is essentially equivalent to one rad.

A convenient means of expressing the effectiveness of a substance in attenuating a gamma beam, that is, in decreasing its intensity, is to make use of a quantity known as the half-value layer. This is the thickness of the material which absorbs half of the gamma photons, fallong upon it and thus reduces the intensity of the gamma beam by one-half. Values of the half-value layer for a number of materials for gamma radiation from Co-60 are as follows:

air	140 m
water	11 cm
aluminum	5.3 cm
iron	1.65 cm
lead	1.06

For example, if the intensity of a gamma beam is 100 mr/hr it would be reduced to 50 mr/hr by 1.06 cm Ph; to 25 mr/hr by 2.12 cm Ph; to 12.5 mr/hr by 3.2 cm Ph; etc. The same effects would be produced by using the same multiples of half-layer values of any materials. It may be noted that it would take an infinite thickness of material to absorb all gamma radiation from a source.

Finally a word, regarding the inverse square law which has many practical applications in the laboratory. If a gamma source can be regarded as a point source and if at a distance d_1 it

intensity is known to be I_1 then the intensity I_x at any distance d_x is given by the relationship

$$I_x d_x^2 = I_1 d_1^2$$

$$\text{or} \quad I_x = I_1 \left(\frac{d_1}{d_x}\right)^2$$

Thus, if the intensity of a 10 mc I-131 source at 10 cm is 231 mr/hr it would be 2.31 mr/hr at 100 cm. This inverse square law assumes a steady rate of emission of photons from the gamma source, with the number falling on a fixed area (1 sq cm) varying inversely with the square of the distance from the source. It is assumed also that no air absorption of photons takes place.

Alpha and beta. In passing through material all the alphas or all the betas from a given source give up their energy by degrees. It can be imagined that each time an ion-pair is formed the kinetic energy of the particle is decreased by 35 ev and this process is continued until all the energy is dissipated. The alpha and beta particles differ from one another in that the heavy alpha particle is more effective than the beta particle in losing its energy. This can be illustrated by comparing 2 mev alpha and beta particles which presumably will produce 60,000 ion pairs before dissipating the 2 mev of energy. The distances traversed by these particles in air and in water before they have lost all their energy in formation of ion-pairs are as follows:

	alpha (2 mev)	beta (2 mev)
air	1.0 cm	815 cm
tissue	.0013 cm	0.9 cm

The distances given in the tabulation above are referred to as the ranges of the particles for the conditions specified. It will be recalled that the alpha particles from a given alpha-emitter all have essentially the same energies and therefore will have essentially the same ranges. The beta particles, however, from a given beta-emitter have a range of energies with the maximum energy being characteristic of the emitter. Hence, if the maximum energy of a beta-emitter is 2.0 mev, the range of the beta given in the tabulation above is the range of the most energetic beta. The ranges of the

other betas will accordingly be less than the figures given. It may be pointed out that since alpha particles dissipate their energies in in such a short range their localized biological effect might be considerably greater than the effect indicated by the energy deposited. In fact their relative biological effect is generally taken as times that produced by the same dose from gamma and beta radiation.

Activation Analysis

This is a method of analysis which involves (1) making the atoms of a given sample radioactive, and (2) identifying the atoms present by their radioactive properties. The method which is quite powerful in certain cases will be sketched briefly.

The method is based on the reaction of a slow or thermal neutron (n) with a target nucleus (T) to form a compound nucleus (C) which is immediately transformed into the product nucleus (P) and a gamma photon (γ).

$$T + n \longrightarrow [C] \longrightarrow P + \gamma$$

When P is radioactive it can be identified by its radiations and its half-life. The activity of the product isotope P produced depends on the number of T atoms present in the sample exposed to neutrons, the intensity of the neutron beam (neutrons per sq cm per second) and a probability factor for the reaction called the cross-section of the target nucleus. The maximum yield of P, generally called its saturation activity is obtained upon exposure of the sample for 3 - 4 half-lives of P. The following tabulation gives the activities produced by exposing one microgram of each of the target nuclides shown, to a rather moderate neutron flux (10^{10} n/cm^2-sec.), for a period of 3 - 4 half-lives. The activities of the product nuclei are given as disintegrations per minute.

Stable target Nucleus	Product Nucleus	Half-life product nucleus	Activity of product nucleus d/m
Mn-55	Mn-56	2.6 h	84,000
Cu-63	Cu-64	12.8 hr	12,000
I-127	I-128	25.0 m	19,000
Au-197	Au-198	2.7 d	170,000

The activities shown are all readily measurable with the usual Geiger counting equipment available in radiochemical laboratories. It may be noted that many reactors now have neutron fluxes 100 to 1000 times greater than the value assumed in the calculations summarized in the tabulation. In other words with the 1000 times greater flux the same activity would result with a target sample of 0.001 microgram.

GLOSSARY OF TECHNICAL TERMS

1. Activity: Frequently used as a shortened form of "radioactivity," it refers to the radiating power of a radioactive substance. Activity may be given in terms of atoms disintegrating per second. See "curie."

2. Alpha emitter: A radioactive substance which gives off alpha particles.

3. Alpha particles: Often referred to as alpha rays, these are positively charged nuclei of helium atoms. They are emitted by radium and other heavy elements and are easily absorbed in a few sheets of paper.

4. Atomic waste: The radioactive ash produced by the splitting of uranium (nuclear) fuel, as in a nuclear reactor. It may include products made radioactive in such a device.

5. Beta emitter: An atom which is characterized by its beta radiation.

6. Beta particle: The name given to the charged electron emitted from certain radioactive nuclei. Also called beta radiation or beta ray.

7. Biologic half-life: The time required for a given species, organ, or tissue to eliminate half of a substance which it takes in.

8. Body burden: The amount of radioactive material in the body at a given time.

9. Bone-seeker: Any element or radioactive species which predominantly lodges in the bone when introduced into the body.

10. Contamination: As applied to radioactive substance, it is the result of mixing a radioactive material with part of one's environment. For example, radioactive fall-out produces contamination of the earth.

11. Curie: A unit of radioactivity which is numerically equal to 37 billion disintegrations per second. It is the amount of radioactivity associated with 1 gram of radium. One curie equals 1000 millicuries (mc) or 1,000,000 microcuries (μc).

12. Decontamination: The process of removing radioactive contamination from objects or areas.

13. Dose: A term used interchangeably with "dosage" to express the amount of energy absorbed in a unit volume or an organ or individual. Dose rate is the dose delivered per unit time. (See also roentgen, rad, rem, rep.)

14. Electron volt (ev): A unit of energy which is gained by a particle of unit electrical charge in being accelerated through a potential difference of one volt. The symbol Kv (short for kev) is used to describe the energy of x-rays.

15. Erg: A measure of energy equal to that required fro an electron to ionize about 20 billion atoms of air.

16. Fission products: Also called fission fragments, these are the split halves of the uranium or other fissionable atom. They include about thirty-six different elements and almost two hundred different radioactivities.

17. Gamma ray: A penetrating ray such as is emitted by radium. In a medical context, gamma rays are more penetrating than x-rays. A gamma ray and an x-ray of the same energy are identical.

18. Half-life: The length of time required for the decay of one-half of the atoms in a given sample. For example, the half-life of radium is 1600 years. If we start with 1 curie of radium (i.e., 1 gram), then in 1600 years we shall have 1/2 curie. In another 1600 years, the amount remaining will be 1/4 curie.

19. Half-thickness: The thickness of a specified absorbing material which reduces the dose rate to one-half of its original value.

20. Hot: A slang word which is widely used to descirbe substances that are unusually radioactive.

21. Ionizing radiation: Electromagnetic radiation (x- or gamma rays, or alpha or beta particles or neutrons) which produces ions as it passes through tissue.

22. Isotopes: Atoms of the same element which differ from each other by having different weight. They belong to the

23. LD_{50}: The dose of radiation which is required to produce death in 50 per cent of irradiated species. Death is usually reckoned as occurring within the first 30 days.

24. MPC: Abbreviation for "maximum permissible concentration." It is that concentration of radioactive material in body tissue which specialists feel will not produce significant injury and may be established as a limit for safe operations in industry or laboratory.

25. MPL: May be either Maximum Permissible Level or Limit. It refers to the tolerable dose rate for humans exposed to nuclear radiation. At present the internationally agreed upon recommendations stipulate an MPL of 0.3 roentgen per week.

26. NCRP: National Committee on Radiation Protection, an advisory group of scientists and professional people which makes recommendations for radiation protection in the United States.

27. NRCS: The name proposed by the authors for the National Radiation Control Service, a federal regulatory agency intended to place restrictions on the use of radiation.

28. Neutron: A basic constituent of all atomic nuclei. Neutrons released in the fission process act as high-speed nuclear bullets and may produce fission in other nuclei or induce radioactivity in them.

29. r unit (or r): The symbol for the roentgen, a measure of radiation dosage. See roentgen.

30. rad: A unit intended to extend the definition of the roentgen to apply to all types of radiation. Technically, it is the absorption of 100 ergs of energy per gram. It is a measure of the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest.

31. RBE: Relative biological effectiveness, the relative effectiveness of the same absorbed dose of two ionizing radiations in producing a measurable biological response.

32. rem: Roentgen equivalent man, a dose unit which equals the dose in rads multiplied by the appropriate value of RBE for the particular radiation.

33: rep: Roentgen equivalent physical, a unit of tissue dosage equal to energy absorption of 93 ergs per gram.

34. roentgen: The standard unit used by radiologists and abbreviated as r. It is a measure of the quantity of absorbed radiation as defined by the amount of ionization produced under specified conditions.

35. Strontium unit (SU): One micromicrocurie of Sr^{90} per gram of calcium, usually in bone but now extended to items of food and milk.

INSTRUMENTATION

John Thorpe*

The following is a list of the use and approximate cost of the various instruments demonstrated by Dr. Thorpe:

	USE	APPROX. COST
1. Non-Amplification instruments		
A. Film badge	Personnel monitoring	$5. ea, including processing.
B. Lauritsen electroscope	Standardization of other instruments. Good sensitivity. For practical purposes, lab. use only.	$200.
C. Pocket dosimeter	Personnel monitoring Good sensitivity.	Charger, $50. Ea. dosimeter, $40.
2. Amplification instruments		
A. Ionization chamber	Field survey, for alpha, beta, gamma radiation. Good sensitivity. Not too rugged.	$350-450.
B. Geiger-Müller	Field survey. Portable or fixed. Excellent sensitivity. Rugged. Beta and gamma only. Very versatile.	Portable, $200.-$300. Fixed, $700 - $1000.
C. Scintillation counters	Usually fixed laboratory analytical instruments. Extremely high sensitivity. Very versatile.	$3000 - 20,000.

We are sorry that the excellent paper of Dr. Ernest Tsivoglou, Robert A. Taft Sanitary Engineering Center was not cleared in time to include in these Proceedings. It may be possible to duplicate and transmit this paper at a later date.

METHODS OF WASTE DISPOSAL*

R. L. Junkins**

The wide range of properties and amounts of wastes requires diversified methods of treatment and disposal to meet all needs. Each class of waste must be considered separately as well as in combination.

Wastes from the atomic energy industry include high activity, intermediate activity, low activity and so called non-active wastes. The different categories are not sharply delineated. "High level wastes" have been defined elsewhere** as those with "concentrations of hundreds or thousands of curies per gallon", whereas "low level wastes" have "concentrations in the range of one microcurie per gallon". Non-active streams are those which normally contain no artificial radionuclides. Accepting these broad categories, including the intermediate level of wastes, for purposes of discussion, the wastes can be further categorized as to physical state and other characteristics.

Because of the wide range in properties of radioactive wastes, alternative approaches to the disposal problem are necessary. The high level wastes are concentrated and stored in such a manner as to isolate the wastes for long periods of time. Low level wastes are usually released to the environs with or without treatment, depending upon the chemical and physical nature of the wastes, the volume involved, the available dilution and other factors.

Containment

Most of the high level wastes are the liquid wastes which result from processing irradiated fuel. These liquid wastes are concentrated and stored in underground tanks. A typical storage tank of the type in use at Hanford consists of a steel liner surrounded by a concrete shell. Provisions for dissipating the heat

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*Dr. R. L. Junkins, General Electric Co., Hanford, Washington.

**Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy Congress of the United States, Eighty Sixth Congress First Session on Industrial Radioactive Waste Disposal.

(This work performed under Contract No. AT(45-1)-1350 between the General Electric Company and the U. S. Atomic Energy Commission.)

generated by the release of energy through radioactive decay are also illustrated. The highly concentrated wastes boil in the tanks, providing an opportunity for further concentration. The condensed vapors can be disposed of by alternate means or re-used in the chemical separations process as make-up water. Through a system of several interconnected tanks, the wastes can be removed to another tank in the event a leak develops. Monitoring of the facility to assure integrity of the wastes storage is required, usually in for the form of inventory of contents and means of detecting leakage into the surrounding soil.

Other forms of containment of wastes are the common practices of burial of solid wastes, either directly in the earth or in subterranean vaults. These wastes are generally of lower-level than the previously mentioned liquid wastes. Depending upon the site, leaching of the radionuclides into fresh water supply may be an important consideration. In any event, the use of this method of waste disposal usually entails control of the real estate for many years.

One approach to the development of economical nuclear power is the "throw-away" fuel concept, in which the fuel is utilized to a high degree of "burn-up" such that recovery of fissionable materials by reprocessing of fuel is not required. Such irradiated fuel elements require storage providing containment and cooling. The cooling medium then becomes a radioactive waste stream.

In general, satisfactory methods of waste containment have been demonstrated during the short history of atomic energy. Much of the current research and development effort is aimed at achieving a satisfactory degree of containment at a reduced cost. In this area some promising work is in progress toward immobilization of wastes through various processes, some involving the use of additives and taking advantage of the heat of the radioactive decay for calcination and fixation. Considerable research has been done toward the possible use of salt mines as storage receptacles for high level wastes.

Release to the Environs

It is neither necessary nor practical to contain and store all radioactive waste materials. Some of the waste radionuclides

are so short-lived that they decay to insignificant levels in minutes. Release of these radionuclides constitutes little problem if control of the immediate vicinity of the point of release is maintained.

In cases where longer-lived, biologically important radionuclides are released to the environs through "low level" waste streams, prompt dilution is usually desirable. Release of wastes to the atmosphere or directly to fresh water is usually done in such a manner as to obtain prompt mixing to the extent practicable. This minimizes the opportunity for reconcentration by physical, chemical and biological mechanisms.*

"Low level" waste streams of small flow rate are frequently released to artificial seepage ponds, where the water evaporates and/or percolates through soil into the ground water. This method of disposal is suited to streams where the content of radionuclides is low enough that surface contamination does not present a problem. In other cases, where the level of radioactive materials fluctuates or is consistently in the "intermediate" range, the same type of disposal is used except that protection from surface movement of the wastes is needed. This is usually provided in the form of a subterranean void space, commonly called a crib, covered sufficiently to avoid wind erosion and shield the radiation.

Ground disposal requires detailed knowledge of the earth sciences of the region including the local geology and hydrology. The capacity of the soil to remove radioactive materials varies greatly with soil type, specific radionuclide, etc. The main advantages of ground disposal are:

1. decontamination of the waste stream by soil,
2. decrease in radioactivity by radioactive decay during the time required for the wastes to reach ground water and flow to a point of potential exposure, and
3. dilution before reaching a point of possible public usage.

Monitoring of the movements of radioactive wastes through the soil is a useful means of determining when the capacity of

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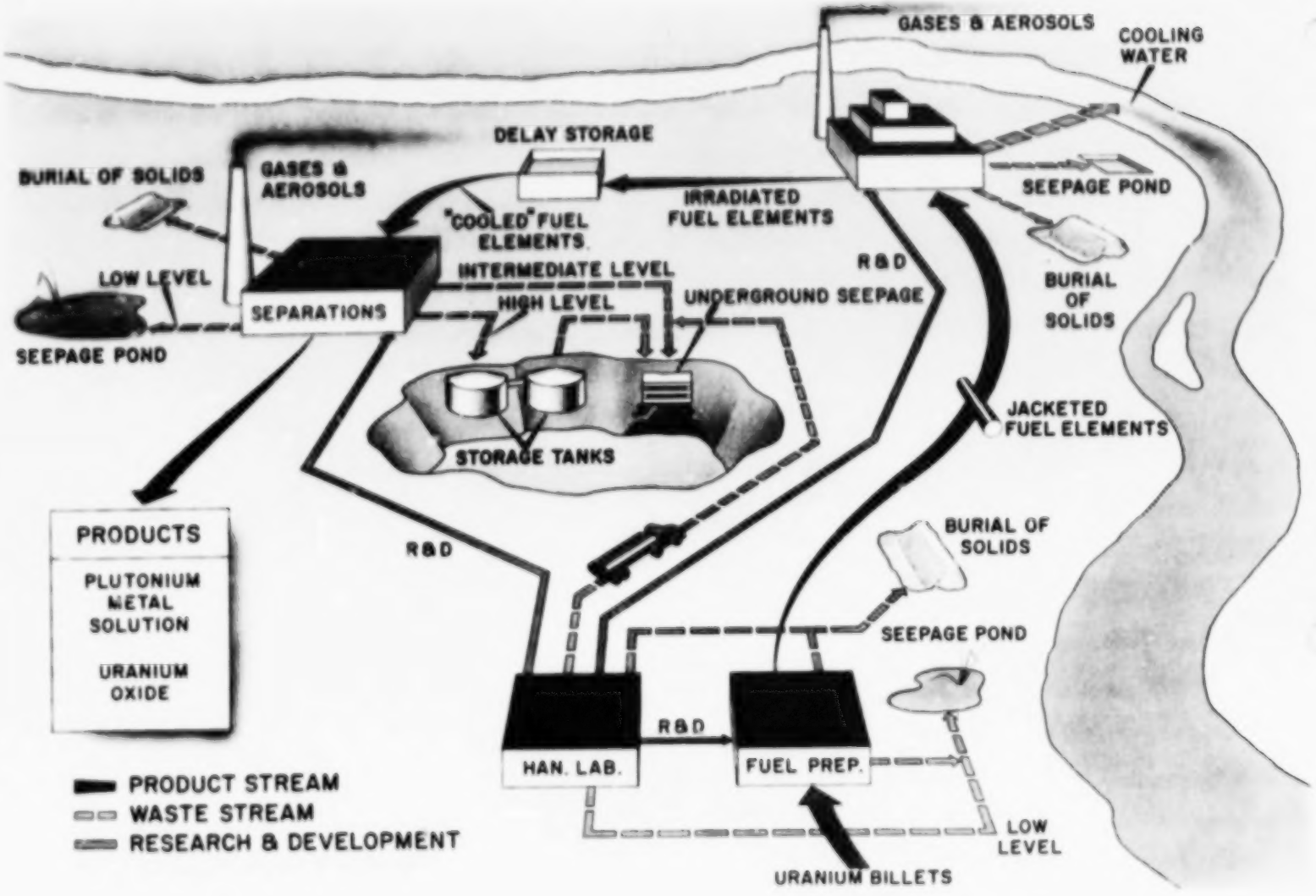
*In some cases, sedimentation near the point of release may be a desirable means of removing radionuclides from the waste. For this and other reasons, prompt dilution is not always advisable.

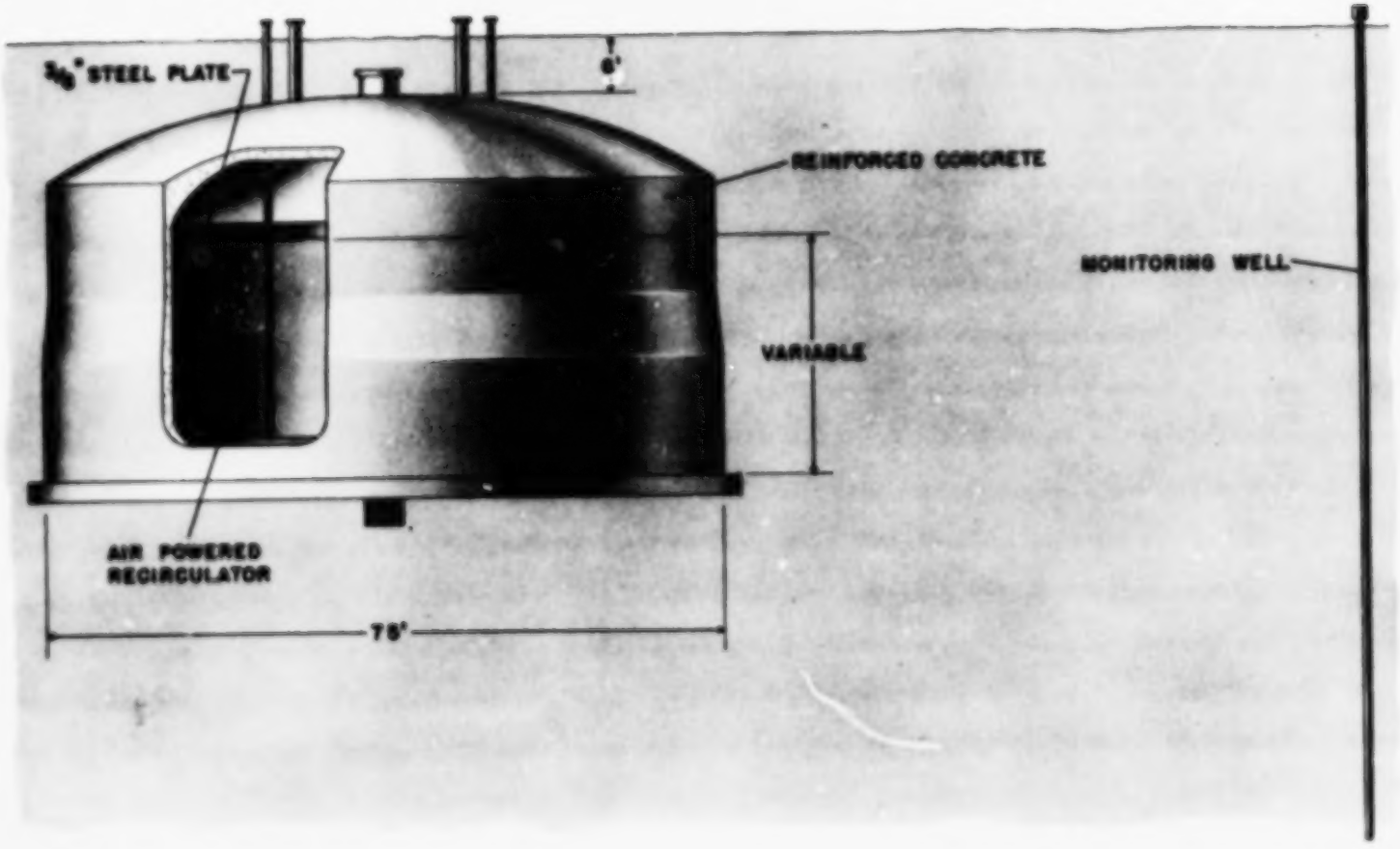
the soil for decontaminating wastes has been fully utilized. Based on monitoring results, the need for a new disposal site can be determined. Movement of the wastes reaching ground water can also be followed and the time when the wastes may reach rivers or other points of usage can be predicted.

The adequacy of waste disposal methods is judged by the resultant radiation exposure to man. Since the early early days of the atomic energy industry, a conservative position has been taken in waste disposal practices not only to keep the exposure within appropriate permissible limits but also to minimize radiation exposure.

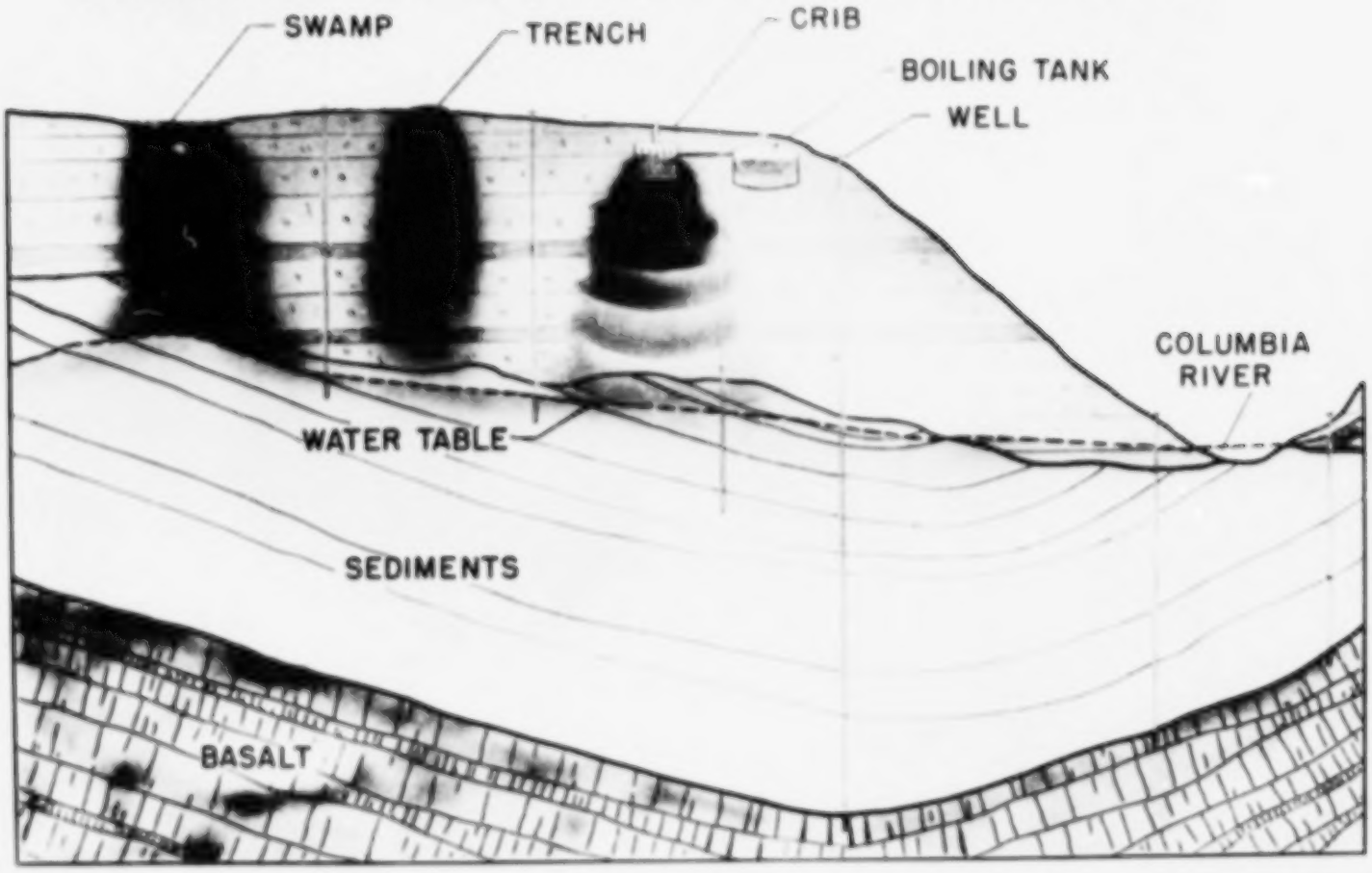
HANFORD PROCESS FLOW CHART



TYPICAL HIGH-LEVEL WASTE STORAGE TANK



HANFORD SITE CROSS SECTION SCHEMATIC SHOWING WASTE DISPOSAL FACILITIES



DISCUSSION

Q: What will be the ultimate fate of the disposal of krypton^{85} to the atmosphere as regards the operations of Hanford and the other power reactors?

A: I was reading a report the other day by a group of consulting engineers in which it was indicated that there are other processes available to remove krypton and other noble gases; however, they are expensive processes. These engineers made some assumptions regarding the growth rate of the atomic energy industry and also presented actual data on its present status. From this they calculate the exposure that would result several decades hence. I believe that they came out with something like 1% of the permissible dose as far as the general population is concerned. I believe that there will be need in some of the power reactors for the control of the release under accident and emergency conditions. The krypton and other noble gas released under accidental conditions could have some very serious effects.

Some states have regulations in this regard. A reactor in Pennsylvania is a case in point. The State of Pennsylvania restricts the discharge to a magic number of 1590 microcuries per day. Frankly, I feel that this regulation is too restrictive and tends to fail to meet the goal of encouraging the development of atomic energy. Atomic Energy Commission has established requirements for General Electric as contractors. Other contractors also have regulations which are somewhat different from those for General Electric.

A: Before a research reactor or power reactor is developed the applicant first must prepare a hazard report for Atomic Energy Commission which takes all of the methods that they will use to prevent the hazard. The report details all of the methods of disposal of waste. These are, of course, thoroughly reviewed and not accepted until there is assurance that the waste situation will be well handled.

A: This will be a problem differing considerably from that of pollution control. In the ordinary pollution control program, each state can operate under its own regulations. Fifty or more types of regulations on atomic energy will not effectively solve this problem. We are going to need a unified system of regulations as the public takes on more and more of the use of atomic energy.

Q: The question regards the coolant water from the reactors which in the case of Hanford is returned to the river. Will we go to other types of coolant, such as organics, to avoid the problem of releasing these radioactive nuclides into the Columbia River?

A: My answer is no. I think it unlikely that we would go to organic material. I think it more likely that we would go to recirculation of water. As a matter of fact, one of the reactors at Hanford is of the recirculation type. The cooling water returned to the river has been described under the category of non-active waste and will not contain radioactive nuclides unless due to corrosion failure in the heat exchanger. The organic coolants have some advantage in addition to cooling, since they perform as neutron moderators.

Q: Do you have anything to say about the life of storage tanks and the degree of saturation of the soil in the disposal areas?

A: Our experience with storage tanks covers 15 or 16 years during which time two leaks developed. In both cases, we removed the contents of the tank to another tank whose integrity was unimpaired, and are in the process of exploring the surrounding soil by drilling wells to learn exactly the pattern of distribution of the radioactive waste. In these particular tanks the waste had aged almost 15 years and accordingly all the short life materials had decayed to insignificant levels. The only radioactive nuclides left in important levels were radioactive strontium and cesium. Of course, we have other thanks in the same location which have never developed leaks. The corrosion experts indicate that the main problem is near the interface, between the liquid and the vapor as far as corrosion is concerned. If a leak develops it is likely to be due to a fine line crack and will be sealed off by the chemical salts. The tanks will probably leak near the liquid line first and we would not loose very many gallons of waste. In answer to the second part of this question, regarding the disposal of waste into the soil, we are fortunate at Hanford in having about 560 square miles of area. In the area where our separation plants are located, the ground water level is at 300 feet. The program is run in such a way that when radioisotopes are detected in the ground water, we avail ourselves of another soil column in the near vicinity and we cease pumping wastes into this partic-

ular column, since the ion exchange capacity has been used up. Most of the short-life material, of course, is decayed before reaching the ground water.

Q: Has any attempt been made to adjust the pH of the waste in order to take advantage of the ion exchange capacity of the soil?

A: The optimum pH has a considerable range and for the most part is on the basic side. There has been little need at Hanford for adjusting the pH.

BIOLOGICAL CONSIDERATIONS OF RADIOACTIVE WASTES IN STREAMS

R. F. Foster*

Although radioactive wastes are often viewed as a kind of pollution with worrisome implications, many of the basic considerations associated with the presence of radionuclides in surface waters are not different from those which apply to non-radioactive materials originating in many phases of our industrial and agricultural economy. For a great variety of toxic materials which are present in effluents, or in the drainage from agricultural areas, we must recognize that it will rarely be economically feasible to remove completely every trace of the substance from the water regardless of our desires to do so. We are faced, then, with the problem of defining the maximum concentrations of many different kinds of toxic substances which, after rational consideration, are generally acceptable. It should be emphasized that the posture on radioactive wastes has been substantially more conservative than for most non-radioactive wastes since the objective has been to restrict the release to the lowest practical level rather than to utilize the capacity of the environment to the utmost.

In a consideration of the biological aspects of a broad variety of toxic materials which may be present in the water, we usually evaluate the potential effects of various concentrations of the substance on (1) man from drinking the water, (2) man from eating foodstuffs which have become contaminated from the water (this is true not only of radioactive materials but of disease organisms, insecticides, herbicides, carcinogens, and many other compounds as well), (3) man from the use of the water for swimming or other recreational or occupational purposes, (4) valuable aquatic life either directly or through effects on its food supply or habitat, (5) domestic animals and wildlife which obtain the toxicants from the water or from contaminated food, and (6) irrigated crops. Obviously, all of these facets of the problem will not be equally restrictive in establishing a maximum permissible concentration.

For a number of substances it may be sufficient to identify the limiting case and proceed with control to a maximum permissible

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limit on that basis. For other cases, including radioactive materials, it will be necessary not only to identify the biological component which is most vulnerable but also to evaluate and combine the exposures received by that component from a variety of sources. Particularly in the case of ionizing radiation, we recognize that a single source of the radiation may be of less interest than the combined dose received from all sources including cosmic and other "environmental" radiation, medical uses, and internally deposited emitters derived from drinking water, foods, and air.

Although the dominant mechanism which leads to biological damage from radioactive materials appears to be the ionization produced in the tissue, this by no means signifies that all radionuclides are similar in biological hazard. Major differences arise because of vastly different amounts and kinds of energy released, rates of radioactive decay, degrees of uptake by organisms, tissue of deposition, and degree of retention. Uptake and deposition are, of course, dependent not upon the radiological characteristics of the nuclide but upon the particular chemical element involved and its chemical and physical state. Of the 92 natural elements ranging from hydrogen to uranium there are over 700 radioactive isotopes. At the present time about 200 of these have sufficient exposure potential to warrant their inclusion in the National Bureau of Standards Handbook 69 - the recommendations of the NCRP on "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure." Thirty-nine of the 200 have half-lives of less than one day and 29 occur in nature.

If we direct our attention to those radionuclides which have drawn some attention as observed or potential contaminants of marine or aquatic organisms, the list would be restricted to about two dozen at this time. Those which result from the fissioning of uranium or plutonium are: Sr^{89}, Sr^{90}-Y^{90}, Y^{91}, Zr^{95}-Nb^{95}, Ru^{106}-Rh^{106}, I^{131}, Cs^{137}, Ba^{137m}, Ba^{140}-La^{140}, Ce^{144}-Pr^{144}, and Pm^{147}. Those which result from neutron activation of stable elements are: (Na^{24}), P^{32}, Cr^{51}, Mn^{54}, Fe^{55}, Fe^{59}, Co^{57}, Co^{60}, (Cu^{64}), Zn^{65}, and (As^{76}). (The bracketed isotopes have half-lives of only a few hours.) Some additions to this list can be expected as reactor fuels, cooling systems, and hardware are modified in the future.

Those radionuclides which are potentially of biological importance in environmental systems have the following characteristics:

1. They are created in sufficient amounts so that accumulation by organisms is possible.

2. Their half-lives are sufficiently long so that they survive to the point of exposure.

3. The energy released by their decay is sufficiently strong to contribute significantly to the total exposure dose.

4. They are accumulated from the water so that the concentration in the organism appreciably exceeds the concentration in the water.

Not all of the isotopes in the above list possess all of these characteristics. Experience to date would suggest that only about a dozen of them can be classed as significant contaminants of aquatic systems. While we should not underrate the potential biological significance of these, neither should we arbitrarily conclude that substantial amounts of any kind of radioactive material will be taken up by aquatic organisms.

The processes by which aquatic forms take up radioisotopes from their environment are identical and coincidental with those by which the stable isotopes of the same elements are taken up from the environment. For example, if the concentration of stable zinc is 5,000 times greater in an organism than in the surrounding water, then we may anticipate that radiozinc in the water will be concentrated by the organism to the same extent. The mechanisms of uptake are adsorption onto exposed surfaces, direct absorption into the organism from the water, and ingestion of the radionuclide with food.

Adsorption is of greatest significance in planktonic forms with large surface-to-volume ratios and also occurs on inert materials which may be ingested by filter or bottom feeding species. Since chemical and physical binding forces are of greater importance than physiological demand in this case, a wider variety of radioelements is "fixed" by adsorption than by the more selective biological processes.

Absorption is of greatest significance in the plant forms which obtain all of their nutrients by this mechanism. It also occurs in the animals, however, and is important in the uptake of calcium and other ions by the gills of fish. The process is selective for elements which are needed by the organism and effectively concentrates the biologically essential materials

in lower forms which are subsequently eaten by higher animals, including man.

Ingestion is the dominant means by which fish and other aquatic animals acquire the materials essential for their growth and metabolism. Because of selective uptake by the gut and elimination of unnecessary materials by the kidneys, gills, etc., the biologically essential elements, including their radioisotopes, are concentrated in appropriate tissues.

Since the chemical composition of different organisms and different tissues varies greatly, the kinds and amounts of radionuclides which are found in them will also vary. Field observations in zones where mixtures of radioisotopes are present have shown that ruthenium will be especially concentrated by certain seaweeds, strontium by lobsters, iron by reef fish, zinc by shellfish and ocean fish, cobalt by shellfish, and phosphorus by all organisms. Because of the broad spectrum of radioactive contaminants concentrated by plankton, it is considered as one of the best "indicators" of the presence of radionuclides.

Although we may sometimes think of the uptake of radionuclides by aquatic organisms from the water or through food chains as a "one-way street" this is certainly not an accurate concept. The relationship between the nuclides in the water and in the biological forms might better be thought of as a complex chemical exchange system in which there is a kind of equilibrium established between the concentration of the nuclide in the water and in the various biological forms, silt, and other exposed surfaces. The rate of exchange between the water and the photosynthetic plants will often be quite rapid. A slower exchange will occur between the various compartments of the community and the vertebrates, especially if the radioelement is firmly deposited in bone or scales. The bottom sediments will often contain an appreciable fraction of the total inventory of the radionuclide. Thus, in considering the capacity of the environment to accommodate radioactive materials, we should include not only the volume of the water, but also the mass of the biota and the sediments.

The accumulation of radionuclides by aquatic organisms can affect radiation exposure considerations in the following areas:

1. A major part of the exposure dose received by the organism is apt to originate from the deposited radionuclides.

2. The edible organisms, such as fish and shellfish, can serve as vectors to funnel the radionuclides to man.

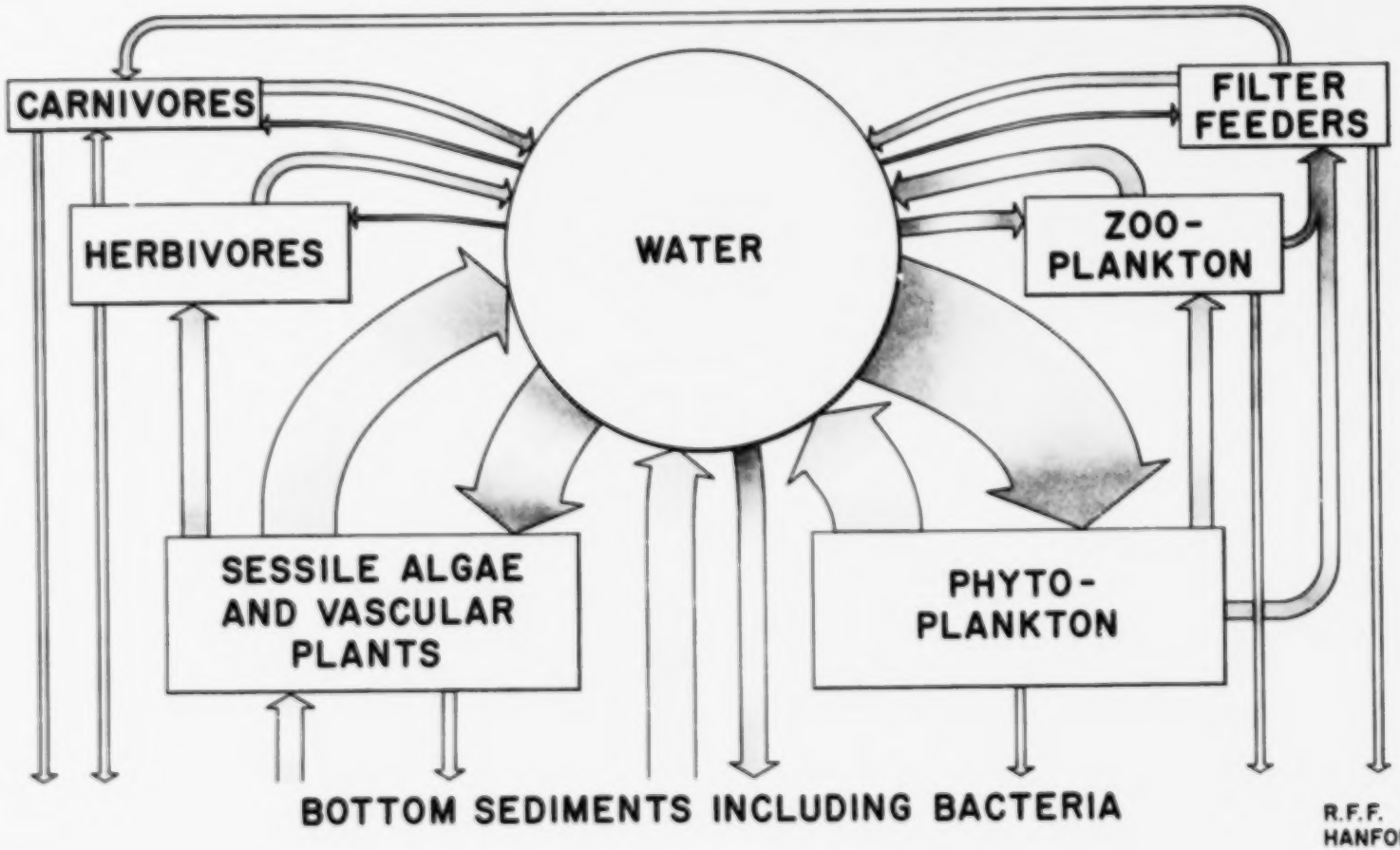
3. Concentration by massed organisms, particularly algae, can increase the exposure dose to persons nearby, e.g., algae growth on boats.

4. The removal of the nuclides from the water by the biota can aid in decontamination.

The volume of information amassed thus far on the effects of ionizing radiation on aquatic organisms is very meager when compared with that available on the more common species used for laboratory experimentation. Nevertheless, a sufficient block of information has been accumulated to permit several generalizations. The lower or more primitive phylogenetic forms are typically more resistant to ionizing radiation than the vertebrates. In broad terms, fish can tolerate on the order of twice the amount of radiation as man, and algae several hundred times this amount. It must be recognized, however, that within this broad generality, there are particular species and particular stages of development which are hypersensitive. An important question, which is as yet unresolved, is whether a complex ecological system might be affected by lower doses of radiation than required to affect individuals within the system.

It seems reasonable to anticipate that in a vast majority of situations where some concern is expressed for the welfare of aquatic organisms exposed to radioactive materials, some of these organisms will be used as food either for man or for domestic animals. The kinds and amounts of radioactive materials present in the organisms must then be evaluated both on the basis of potential radiation effect to the organisms and on the acceptability of the edible forms as food. Available information points to the use of the organisms for food as being substantially more restrictive on the maximum permissible concentration of radionuclides in the water than the potential radiation damage to the biota. Here again our knowledge is limited, however.

EXCHANGE OF RADIOPHOSPHORUS BETWEEN WATER AND BIOTA



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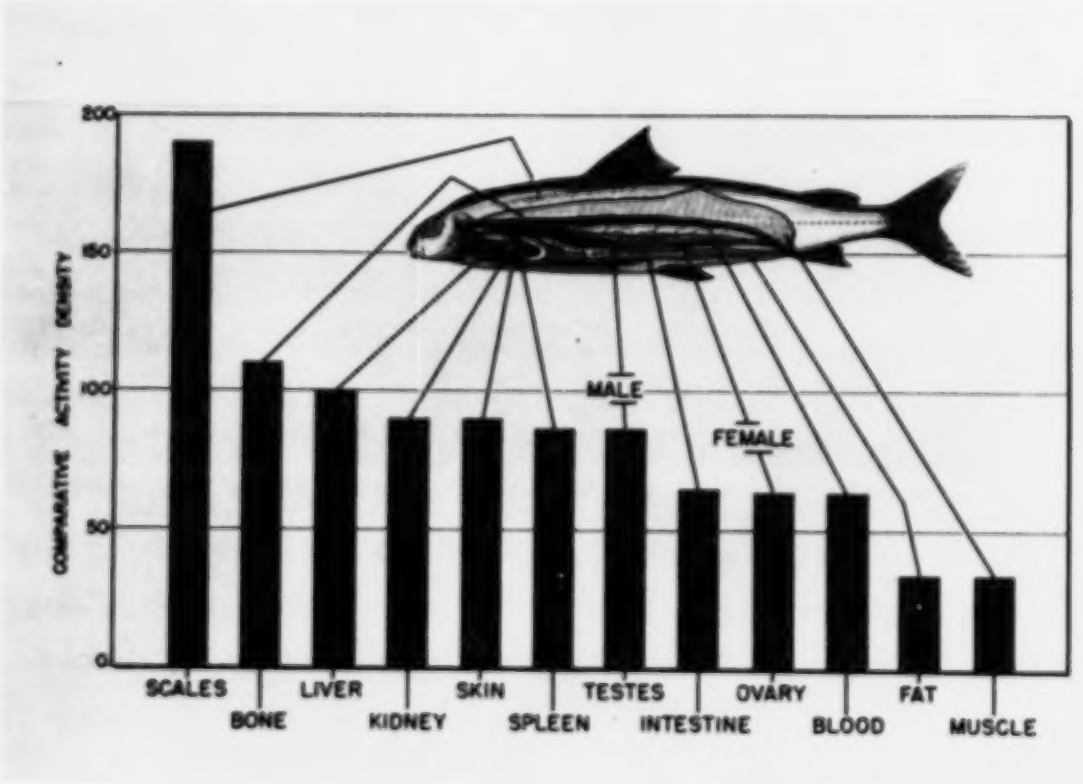
RADIOACTIVITY IN DIFFERENT TISSUES OF COLUMBIA RIVER FISH



DISCUSSION

Q: Where do migratory waterfowl appear on the chart regarding the tolerance to radioactivity?

A: Presumably, it will be between man and fish, and that is near the bottom, or point of lowest tolerance. Actually, man should not appear on this chart. We are not interested in killing man, but in protecting him from genetic damage. This is where the permissible dose levels fall down. Naturally, there will be different criteria established for fish and other organisms than for man.

Q: In what terms are these units on the chart?

A: These are in terms of the total radiation dose or roentgens of radiation in which the organism is placed in a field of gamma radiation for a specified length of time.

Q: How much of the total radiation in the Columbia River is due to Zn^{65}?

A: It is of an order of magnitude less than P^{32}.

Q: Does it have any significance on fish as food for man?

A: If we look at the comparative intake rates of the several isotopes, P^{32} amounts to about 95% plus. Zn^{65} is the next most abundant isotope in the order of about 2%. Because of the abundance of the P^{32} versus the zinc and also because of the fact that the permissible intake rate of Zn^{65} is greater than P^{32}, the contribution which Zn^{65} makes to the total exposures of the individual who is eating the fish puts this down probably in the order of 1%.

PROBLEMS OF THE ADMINISTRATOR

Ely J. Weathersbee*
and
Curtiss M. Everts**

We are pleased to have this opportunity to present some of the problems we have encountered in developing the radiological health program in Oregon, and we hope that in the open discussions that follow this presentation, we can count on some helpful suggestions from those present. In an effort to avoid repetition and because of the similarity of problems in the two states, the material to be presented has been divided into two general areas; one of which we will present, the other to be presented by Mr. Stockman of Washington.

Ever since the detonation of the first nuclear device, pollution control administrators have wondered what effect the future developments in nuclear energy might have on the quality of water for which they are responsible. This curosity continued subsequent to 1946 when the Atomic Energy Commission was established to place atomic weapons under civilian control. It became even more evident in 1954 with the adoption of the Atomic Energy Act of that year, that if the development and regulation of peaceful uses of atomic energy were to be undertaken, that state and local governments would have to gain additional intelligence on the subject and develop programs for local control.

While some of the more populated states were able to undertake the development of programs and the training of personnel, the states with small populations found it difficult to obtain funds to initiate programs, particularly since the responsibility for regulation apparently still rested with the Federal Government. Despite these handicaps, however, state health agencies and state water pollution control groups, cognizant of the problems that they were to face in the future, began in at least a modest way to train personnel and to assemble laboratory equipment in an effort to gain a better knowledge of the problem and to initiate limited surveillance programs.

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*District Sanitary Engineer, Oregon State Board of Health
**Director, Division of Sanitation and Engineering, Oregon State Board of Health.

In 1959 Congress amended the "Atoms for Peace" Act to permit states to share the regulatory responsibility with the Atomic Energy Commission whenever a state could show that they were capable of carrying on such work effectively. Essentially, the criteria under which a state may assume some of the regulatory authority formerly exercised by the Atomic Energy Commission are as follows:

1. A state must demonstrate a program (including laws, regulations, personnel and facilities) capable of adequately protecting the health and safety of the public.

2. The State's program must be compatible with and essentially the same as that of the Atomic Energy Commission.

It is the responsibility of the water pollution control administrators to effectively manage the quality of all surface and underground waters to the end that they may be used for beneficial purposes. Surface waters must be preserved as sources of domestic, industrial and agricultural water supplies, for the propagation of fish and aquatic life, and for the recreational enjoyment of the people.

Ground waters must be preserved for domestic, industrial and agricultural water supplies. It is obvious, therefore, that the discharge of waste containing radioactive materials into either surface or underground waters would promptly become a matter of concern to the pollution control administrator. In the course of these events, standards establishing the maximum permissable concentration of radioactive isotopes were in the process of development, and while they have achieved a high degree of acceptance among some scientists in the field, there are others, and particularly the public, who may not agree with them until they have been completely satisfied that the levels suggested are absolutely safe.

The states began to adopt their own enabling legislation and regulations after 1954 when the peaceful uses of atomic energy were under more extensive development. The law in Oregon was adopted in 1957. It named the State Board of Health as a regulatory agency, established a five man advisory committee for the Board, and directed the State Board of Health to promulgate regulations on the subject of radiation protection after first making a two year study of the problem. The present status of the Oregon program is as follows:

1. The program is being directed within the State Board of Health by a six man intradepartmental committee -- advised by the five man Advisory Committee as provided by the 1957 statute.

2. Regulations have been prepared, approved by the Advisory Committee, and will be presented to the State Board of Health for consideration for adoption at their December meeting.

3. Budget requests have been made for four staff positions and approximately $13,000 for equipment for the 1961-1962 biennium.

4. A staff training program is being conducted within the department and advantage is being taken of available short course training to the greatest extent possible without neglecting other duties.

5. A member of the staff routinely accompanies Atomic Energy Commission inspectors on their visits to licensed installations within the State.

6. The City of Portland and the State Fire Marshall are kept currently advised of locations of Atomic Energy Commission licensed installations.

7. Our Air Pollution Control Section has participated in both of the National Air Surveillance Networks since the inception of these programs, and our laboratory personnel have participated in the analytical reference service program at every opportunity.

8. A tentative environmental surveillance program has been formulated and will be implemented immediately if our budget requests are at all favorably treated.

9. A request for funds from the Public Health Service for a study project on the Columbia River has been submitted and is currently under consideration by them.

We still have a few things that must be done such as:

1. Obtain changes in our Radiation Protection Law to permit assumption by the State of regulatory duties from the Atomic Energy Commission.

2. Revise or supplement our regulations to provide for licensing of radioisotope users and otherwise satisfy Atomic Energy Commission criteria.

3. Establish laboratory facilities, develop staff competency, and implement the surveillance and regulatory programs.

In the accomplishment of these objectives we would naturally anticipate that a great deal of correlation of activities would be necessary between the various federal and state agencies who have an interest in this field. In addition, local agencies such as health departments, fire departments and others, may be expected to develop a much keener interest in the subject. Certainly one of the prime responsibilities of the state agencies would be to keep these groups informed of its actions and procedures.

We have quite a way to go before we have an adequate and complete program in operation in Oregon. However, we feel that the situation is not so critical that we cannot meet the need provided that we do not drag our feet from now on.

In summary ---

We are in the early stages of a move from strict federal control of radioactive sources to joint Federal - State - Local regulation more in line with the usual handling of the more commonplace pollutants.

Our state program should eventually involve licensing, inspection, and enforcement of regulations, monitoring of the environment, coordination with federal and local activities, including making available to them the information necessary to satisfy their needs.

We would look to the Federal Government to maintain control over reactors and other activities which could result in widespread contamination, regulate ocean disposal of wastes, coordinate waste disposal practices among the states, regulate interstate transportation of materials, provide consulting services to the states, develop standards, and promote research.

Radioactivity is relatively new as a pollution problem requiring specialll trained staff, special equipment, and "education" of the public so as to keep the problem in its proper perspective -- (these are the areas to be covered by Mr. Stockman).

PROBLEMS OF THE ADMINISTRATOR

Robert L. Stockman*

The remarks prepared by Mr. Curtiss Everts and Mr. Jack Weathersbee of the Oregon State Board of Health have dealt with the Areas of Interest and Legal Aspects as they relate to the problems of the administrator dealing with radioactive wastes.

In order to avoid duplication, I will not discuss these areas except for incidental reference. My remarks will relate largely to Recruitment and Training of Personnel, Laboratory Resources, and Public Information.

In considering the problems of the administrator, it is not possible, nor even practical, to separate the waste disposal problem from the total problem of population exposure to ionizing radiation for at least two reasons.

1. Human exposure to any source, natural, or man-made, is of concern.

2. In order to effect the necessary control, all sources will ultimately come under surveillance or cognizance.

In developing physical and personnel resources, program criteria, and controls, the administrator will take into account all sources of ionizing radiation, the occurrence and movement of radioactive material in the environment, and then determine the attention needed in each area. Broadly state, the areas of concern would include medical, industrial, waste disposal, disaster, weapons testing, and miscellaneous.

The question of research presents at least two important questions to the administrators, as follows:

1. What is to be done? There is no doubt need for further research in the areas of biological effects, methods of environmental surveillance and investigation, and data evaluation which can be of extreme importance to the improvement of radiation control programs.

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*Mr. Robert L. Stockman is Engineer in Charge, Air Sanitation & Radiation Control Section, Washington State Department of Health.

2. Who is to do it? Research work at the Federal and private enterprise level is relatively well on its way. The administrator at the state and local level does well at the present time to keep abreast of what is going on. But, in looking to the future, he must make a choice of waiting for developments nationally, supporting or cooperating in nation-wide research, and supplementing these with his own research arm, at least for special problems. If he is to maintain a research arm, it may put a very different fiscal and organization complexion on his program and call for specific additional needs in equipment and personnel resources. It is likely that his own research activities will be somewhat limited, but there is no doubt that he should cooperate in nation-wide research activities and, where justified, support research activities.

With this background, let us look at a few of the specific problems.

Recruitment and Training of Personnel

This presents perhaps the most difficult problem. While the pool of trained people is growing, it is still more than a fiscal problem in view of the relatively limited supply of people. This is particularly true in the case of a state agency which is usually in not too good a position in the competitive market.

Under this circumstance, while a state agency may hopefully recruit for experienced personnel, they will largely depend upon recruiting younger personnel with a good potential and capable of utilizing the training opportunities that can be offered. This approach is not necessarily undesirable, but it does retard the early development of needed programs. One experienced man could enhance the progress to a very great extent, provided he has men of good potential assigned to him. The problem then begins to resolve itself to:

1. The recruitment of men with good potential and the provision of training opportunities for them and

2. The recruitment where possible and paralleling number 1, of at least one experienceddperson.

If the program is to have any research activity, different personnel needs occur. A research activity does not seem an appropriate part of a control program in its initial years. This

is not to say that a control agency should not stimulate, support, or cooperate in research nor that it should not develop a research arm as a second important program phase.

In general, the state can look with some confidence to the training resources available from the A. E. C., the Public Health Service, and institutions of higher learning, and, by utilizing them to the maximum, will be fostering the development of a pool of experienced personnel.

Laboratory Resources

From the fiscal standpoint, we get about what we pay for as far as physical facilities are concerned. The cost of a facility for environmental surveillance of radioactivity may easily range from $2000 to $100,000 depending upon the objectives and sophistication of the program. The effectiveness of the laboratory, however, is entirely dependent upon the quality of personnel assigned and the two cannot be separated.

In planning for the future, the administrator must look very closely at the needs, the objectives, and the physical problems. There seems little question as to need and objective in the broad sense in that there will undoubtedly be more, rather than less, environmental surveillance in connection with control programs and that the evaluation will require more refinement as to types, transport, and concentration of radioactivity. This, then, leads to projecting criteria for the physical laboratory needs. First is the laboratory space as to size and location. One would be most fortunate to be in the unlikely situation of being able to place a facility of any permanency in existing laboratory space or in remodeled office space. The requirements for basic utilities (plumbing, wiring, ventilation, and air conditioning) shielding, sample preparation requirements, and room for expansion are cause for very serious consideration in making an early decision as to location. Second is the problem of programming the purchase of specialized equipment. This should be done with considerable caution considering the needs and capabilities of the laboratory in any given time, the integration of component items in a scheduled purchasing program, the capability of equipment maintenance, and caution as to the problem of obsolescence that may result from over-purchasing.

Some consideration should be given to space requirements for potential research activities, but, again, this will not usually be an early part of the program.

Considering the two problems of personnel and laboratory resources together, we might look at an example. Appendix I shows the approximate sampling schedule and reflects the capability of the laboratory recently completed by the California State Department of Public Health. This would not appear to be a large scale program although, relatively speaking, it is larger than most states have to date. Water and sewage represent less than 10% of the environmental sampling to be done. As we move from the gross beta and alpha capability to the strontium-90 and gamma scan capabilities, basic space and equipment requirements can easily increase tenfold. To accomplish the schedule indicated in the table, required expenditures for equipment of $63,000; for basic laboratory space, including hoods, benches, and utilities, $42,000 and for personnel (1 year) $83,000, or a total of $188,000 for the first year's operation. To most state agencies this would appear to be a tremendous sum and yet it is fairly conservative after careful examination. Basic equipment includes automatic low-background G-M detector for strontium-90, window-less gas flow proportional counting for gross alpha or beta, single channel gamma analyzer and scintillation well crystal for single gamma emitters, and a 256-channel analyzer with 6-ton steel shield and 4 x 4 scintillation crystal for unknown gamma mixtures. Personnel include 8 chemists, one instrument technician, 3 laboratory assistants, and two clerks.

Such a program may not be necessary in some locations but may be more than justified in others. This is a decision which the administrator will have a large part in making. Suffice it to say, however, that short of a legislative windfall, careful fiscal planning is required. The utilization of outside resources may be particularly important, at least in the early stages. These would include the laboratory resources and training opportunities potentially available from the A. E. C., from the Public Health Service Taft Sanitary Engineering Center, and the Southwest Radiological Health Facility, and institutions of higher learning.

In any event, the states will begin to move in the collection of environmental surveillance information. The results of research could be helpful here to provide improvements in surveillance, techniques, and equipment and methods. Particularly important might be the development of isotopic indicators for specific situations. For example, in the case of Hanford discharges to the Columbia River, it would be most helpful if analyses for a limited number of specific isotopes might be found to provide sufficient information for routine purposes as to the presence and concentration of other isotopes. The evaluation of the collected data will be a logical objective and here further research in the transport, uptake, and effect of radioactivity would be most helpful.

Public Information

The problem of public information is not unique to the radiation area but can have very dramatic repercussions. In general, the administrator would like to be in a position to reassure the public. Sometimes he can do this on the basis of reasonable judgment factors in the absence of specific data, but he would be much better off if properly equipped with information. There are several areas in the problem as follows:

1. Public information related to a major Atomic Energy installation, existing or planned. Here he must be equipped with information as to the nature of the installation, the beneficial use involved, and the degree of probable hazard. He should be in a position to determine and state that the probable hazard is minimal, or that it is sufficient to require preventive or corrective action. He will be involved with an interested public on the one hand or an aroused public on the other.

2. Radiation incidents or disasters. We all know how the public can react to any rumor relating to an incident. We have had several episodes in Washington which involved rumor of the presence of radioactive material, rumor of the spread of radioactivity into public areas, and rumor of actual radiation injury. Fortunately, the facts were not as rumored, but rumor is much more difficult than fact in handling the public information. Fortunately, with careful handling through the news media, the situations were adequately handled, but had come very close to serious public alarm. The administrator then must be prepared not only for the rumor problem, but for proper public information in the event of an actual incident.

3. General information. As the uses of radiation increase in number and variety, it is well to maintain a continuing program of information to the public about these uses, the probability or lack of probability of hazards, and the control to prevent hazards. A proper conditioning of the public in this manner should do much eventually to offset public information problems associated with 1 and 2.

Let's look at an example of a potential public information problem in our area. The fact that radioactivity has been found in shellfish would make an interesting news story. Should this happen without adequate explanation by responsible authorities, needless emotional outburst and probable economic injury due to buyer resistance could result. I merely place the questions here,

"How well prepared are we to handle such a problem?"; "Do we have sufficient factual information to make an authoritative statement, or must we act on general assumptions which we hope are reasonable?" The fact that there has been a minimum of concern among the local population in the Hanford vicinity is in part a credit to public information activities and in part, I am sure, due to the fact that the population has grown up with the installation since its early days. But, supposing we were to go in now to make a rather thorough study of the occurrence of effects from radiation in that local population. It appears to me that this is one of the most likely places in the world to make such a study. Here is a sizeable resident population exposed to radiation over a long period at environmental levels which could be fairly well estimated. I believe such a study should be made as one of great national interest. The public information aspects of such an effort would be one of its most important elements. Here we have a population group long conditioned to the thought that there is no hazard, suddenly being asked to serve as laboratory objects. I am sure that it can be done, but it must be very carefully handled.

In summary, the states have a continually increasing role in the control of radiation as it affects the public health and welfare. They will have increasing legal responsibilities in addition to their existing moral responsibilities. They will be interested in all sources of radiation exposure, one part of which has to do with activity in our water courses as a segment of the environment. The administrator faces problems which are challenging but not insurmountable. Among these are the problems of personnel recruitment and training, the development of laboratory and other physical resources, and a very important one in public information. The results of past and continuing research will have a bearing on the objectives and means of accomplishing his program. In the early stages, a development of his own research arm is not likely, but it is important that he follow research efforts, suggest research needs and support or cooperate in research. Ultimately, he may develop research activities to meet the needs of certain of his program areas.

DISCUSSION

Q: How do you expect to train your staff in the radiation field? Do you propose to send them to universities and colleges?

A: Yes, we have done this traditionally in other areas of our operation. Training will be accomplished by means of a combination of formal graduate training and short courses, and by placing men in in-service training in such places as Hanford, Las Vegas and the Center. At the University of Washington the Department of Biology has a summer institute for this type of training under a National Science Foundation grant.

Q: Do you have any idea regarding the amount of trained personnel in this field in Washington? How many trained teachers are there?

A: Probably, outside of captivity, there aren't very many. Because of the presence of Hanford, there are probably more people of this type in Washington than in any other state in the country. We have several people in the medical radiation field. Practically none in private industry or public activity outside of institutions of higher learning.

Q: Is it possible that the states may choose to have more restrictive regulations than those set forth by the Atomic Energy Commission or the Public Health Service? If so, is there any conflict here?

A: There should be no conflict. However, it would be rather inappropriate for a state to go into the waste phase without going into the whole radiation field. The waste disposal problem is a comparatively small part of the total program.

Q: In the State of California, the State thought that the disposal of wastes at 1,000 fathoms (required by AEC) in the ocean was not deep enough, and went to 2,000. What would be your reaction to this?

A: We have not faced this problem in the State of Washington, since we have no formal contractors for the disposal of radioactive wastes into the sea. The selection of 1,000 fathoms was arbitrary, and no doubt the deeper the better.

FUTURE USE OF ATOMIC ENERGY--PROJECT CHARIOT, ALASKA

Allyn Seymour*

Ideas for the future use of nuclear detonations for peaceful purposes are being studied by the U. S. Atomic Energy Commission. The program is known as Plowshare, of which one part is Project Chariot. The various projects in the Plowshare program are typical of ways in which nuclear explosives may be used in the future. At the present time a moratorium at the request of our government prohibits the detonation of nuclear devices for any purpose.

The Plowshare projects in general are underground explosions in which none or only part of the radioisotopes that are produced escapes to the atmosphere. As a consequence the question arises, "What will be the contribution to the radioactivity in our environment by nuclear detonations for peaceful purposes?" or as the biologist might ask, "What will be the biological cost?". The following discussion will not provide specific answers to these questions but will explain the types of projects that are envisioned, especially Project Chariot, and in this way partially answer these questions in a general way.

The Lawrence Radiation Laboratory at Livermore, California initiated the Plowshare Program and as early as February 1957 a symposium was convened there to discuss ways in which nuclear explosions could be used for other than military purposes. The name, Plowshare, was suggested by the passage in the Bible that reads, "..... and they shall best their swords into plowshares, and their spears into pruning hooks; ....." (Isaiah 2:4).

In considering projects that might be suitable for the Plowshare program it was recognized that nuclear explosives differ from chemical explosives in that they are big and that they produce radioisotopes. The great size of the nuclear explosives meant that primary consideration was to be given to projects that would be larger than the largest projects in the past with chemical explosives, for example greater than the 1300 tons of TNT used to remove Ripple Rock in Seymour Narrows,

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British Columbia. The problems created by the production of radioisotopes can not be eliminated but can be minimized by the use of a "clean" device, that is, one in which the ratio of fusion to fission is high, and by containing the radioisotopes underground. With these considerations in mind projects in the following categories have been suggested:

1. Civil engineering. Large volumes of earth and rock can be moved with nuclear explosives at costs below those of conventional methods. For detonations in which the yield is about 2 kilotons or less the use of high explosives is cheaper, but at 10 and 100 kiloton yields nuclear explosives are cheaper by a factor of about 3 and 25 respectively (Griggs and Press, 1960). Projects to be considered in this category include the excavation for a harbor, the digging of a canal or the removal of a navigational hazard.

2. Oil recovery. Three methods have been suggested.

a. Tar sands. The oil in tar sands, a mixture of sand and crude oil, cannot be extracted by conventional techniques. It is believed that the heat released by nuclear explosives will lower the viscosity of the oil in the sands sufficiently to permit recovery by conventional means.

b. Oil shales. By fracturing oil-bearing shales oil can be released or recovered by in-place heating followed by pumping.

c. Secondary recovery. Most oil fields, when depleted by conventional recovery techniques, still contain appreciable quantities of oil. Heat and blast effects from a nuclear explosion could be utilized in secondary recovery of this oil.

3. Power and isotope production. The energy released and trapped by fully contained nuclear explosions offers a possibility for use in both power and radioisotope production. The heat produced by the explosion would be contained underground and released in a controlled manner by use of a transfer agent such as water, carbon dioxide or nitrogen, and used either directly or in the production of electric power. At the same time an appropriate substance placed near the detonation would be bombarded by neutrons and in this way produce radioisotopes.

4. Mining. After the fracture of low-grade or inaccessible ore deposits, or deposits where the hardness of the

rock makes the use of high explosives uneconomical, minerals would be recovered by leaching in place or other conventional mining methods.

5. Water resources. Possibilities in this category include regulation of underground flow of water, water storage and the production of fresh water from sea water by utilizing the heat produced in an underground explosion.

6. Scientific uses.

a. Seismology. Controlled nuclear explosions may improve one hundredfold the information that is needed to determine the earth's structure.

b. Physics. If neutron-rich isotopes of element 102 and heavier are to be made, the job probably will be accomplished by using a thermonuclear explosion as the neutron source (Cowan, 1959).

c. Meteorology. Nuclear explosives are not likely to be used to control weather but might have some influence on a specific storm.

Of the projects listed above some are impractical at the present time. However, for two, some studies are currently under way. "They are: Project Gnome which is a proposed detonation of a 10-kiloton device in the salt beds near Carlsbad, New Mexico, for the purpose of investigating the feasibility of recovering power and isotopes, and Project Chariot which is a proposed experiment to use two 200-kiloton and three 20-kiloton devices to demonstrate the feasibility of excavation for such purposes as harbors and canals. In addition, there have been discussions with the petroleum industry regarding its interest in supporting an AEC-U.S. Bureau of Mines project to investigate the practicability of using nuclear devices to crush oil shales thereby permitting the recovery of oil by in situ retorting. ..... Thorough consideration is being given to every phase of these projects and the Commission requires that every precaution be taken to assure the public health and safety." (Shute, 1959).

The Gnome detonation will be contained entirely underground without release of energy or radioactivity to the atmosphere, whereas the devices for the Chariot Project will be so placed that the surface above the devices will be excavated. The excavation will not extend to the depth at which the de-

vices are placed but will allow the escape of a small part of the radioisotopes that are produced. Kinds and amounts of radioisotopes to be expected from Chariot can be predicted by extrapolation from data obtained from the detonation of small underground devices in Nevada; however, one of the objectives of the Project is to obtain information from which the accuracy of these predictions can be improved.

The site of the proposed excavation is on the northwest coast of Alaska below Cape Thompson at the mouth of Ogotoruk Creek. The simultaneous detonation of the five devices would produce an excavation with a basin about 550 by 900 yards and a channel about 250 by 600 yards that would be accessible to the Arctic Ocean. Minimum depth would be about 30 feet. (A recent change in the devices to be used from two 200-KT and three 20-KT to one 200-KT and four 20-KT devices will slightly alter these dimensions). The smaller devices would be buried at a depth of about 400 feet and the larger at 700 feet.

The phenomena that occur when the devices are detonated (called the phenomenology of underground explosions) can be explained by associating the occurrence of various phenomena with time-periods. The Rainier event (a part of Operation Plumbob in Nevada in 1957), in which 1.7 kilotons of energy were released in a room 6 feet square, 7 feet high, and 800 feet below the surface of the earth will be used as an example. There are four major time-periods:

"a. Nuclear Phase (Microseconds). The energy of the nuclear explosive is generated in a few tenths of a microsecond, vaporizing the assembly materials and forming a rapidly growing fireball. The material in the Rainier room reached a temperature of ten million degrees Fahrenheit and a pressure of seven million atmospheres.

b. Hydrodynamic Phase (Milliseconds). A shock wave proceeds outward vaporizing, melting, and crushing the surrounding medium. A cavity is formed by the outward motion of the rock near the center of the explosion. In Rainier, the shock vaporized a 3-foot thickness of rock (about 100 tons), melted 7 more feet (about 600 tons), and crushed rock out to 130 feet. The cavity in Rainier reached its final radius of 55 feet in about a hundred milliseconds.

c. Quasi-static Phase (Seconds to Minutes). The cavity cools and collapses when the internal pressure can no longer support it. In Rainier, the pressure dropped to forty at-

mospheres in about a minute. A fissure must then have opened, allowing the gases to escape and releasing the internal pressure; the roof caved in and a chimney of rubble was formed. About two hundred thousand tons of broken rock were produced.

d. Long-term Phase (Days to Years). A slow transport of heat through the rock takes place, and the radioactive products decay. In Rainier, the water present in the rock (20% by weight) vaporized and distributed the heat over a large volume; the highest temperature now present is at the boiling point of water." (Johnson, 1959).

During the nuclear phase radioisotopes are created by fission of the fuel material and by the capture of neutrons by stable isotopes in the assembly materials and in rocks within a meter or so of the detonation point. Therefore, the kinds and amounts of various nuclides produced by underground explosions are determined by the kind of explosive (i.e. all fission, or part fission and part fusion), and by the composition of the rocks (and assembly materials) immediately adjacent to the detonation point.

Most of the radioisotopes are trapped in the fused material formed by melting rock during the period the cavity is enlarging (hydrodynamic phase). This is explained by Higgins (1960) to happen in the following manner. "When the temperature of the gas reaches the condensation point of some rock constituent, say about 4000° K for a rock containing CaO, that constituent begins to condense into a liquid and scavenges the gas phase of all radioactive species which have equal or higher condensation temperatures. This condensed material forms into droplets and mixes with material melting on the wall surfaces. As lower and lower temperatures are attained, more and more radioactive species condense into the liquid phase."

The radioactive species that do not condense at the melting point of rock and remain in the gas state migrate through fissures that form during the quasi-static phase and, except for the noble gas fission products Kr and Xe and for tritium (if present), condense on all of the available surfaces. Hence radioisotopes from underground detonations may be found in the fused material, on the surface of fissures and broken fragments or in the permanent gas phase.

The precursors of biologically important Sr^{90} and Cs^{137} are 33-second Kr^{90} and 3.8-minute Xe^{137}, respectively. Because the half lives of the precursors are short the amount of

Sr^{90} and Cs^{137} that escapes, or, conversely, the amount that is contained in the fused material depends upon the length of time the cavity stands before collapse. If the cavity collapses one second after the explosion, about 20 percent of the total radioactivity is in fused material, 70 percent in the broken rock and on fissure surfaces, and 10 percent in the permanent gas phase. If the cavity collapses 30 days following the explosion the values are 85 percent, 5 percent and 10 percent respectively. In the first case, most of the isotopes that have rare gas precursors, such as Sr^{90} and Cs^{137}, would escape or be on the broken rock surfaces; in the second case, most of the Sr^{90} and Cs^{137} would be incorporated in the melt.

With all or most of the radioactivity remaining underground the question arises, "Does the ground water become contaminated?" The answer is that it does only slightly, except for tritium. There are three reasons for this condition. First, the bulk of the activity is bonded in an insoluble, unleachable glass; second, the ion-exchange property of the rock ultimately removes the radioisotopes from the water. When water comes in contact with contaminated rocks, small portions of each remaining radionuclide enter the water solution. However, the radioactivity which enters the water is transferred to other rocks as the water moves into an uncontaminated region. An exception is tritium (produced by thermonuclear explosions), which will move more or less with the percolating water. And third, the detonation produces a zone of finely-divided, unclassified material which acts as an impermeable barrier to water flow. Expressed in percentages, the insolubility accounts for removing about 90 percent from availability, ion exchange removes more than 99 percent of the remaining 10 percent, and the water distribution probably removes 60 percent of the remaining 0.1 percent for each zone traversed. In short, within a few feet all of the radioactivity is absorbed on the mineral. (Higgins, 1959).

Higgins (1960) also has summarized the effects of radioactivity upon other Plowshare projects. "The amount of radioactivity which would contaminate an ore zone if it were in the collapse region can be estimated, and is found to be very small. Human occupations in such an ore zone should not be restricted after the explosion, and the only detriment to product values might be their technical contamination. (Contamination which would preclude using copper in camera parts or silver in making photograph film emulsion). None of the properties of either petroleum products or the explosives produced radioactivities indicate that petroleum would be

contaminated if nuclear explosives were utilized at some step in their recovery. Use of thermonuclear explosives in the development of water resources should be approached with great caution because of the possibility of tritium contamination, however, the fission products and induced activities will not lead to contamination problems in regions where the earth minerals have normal adsorption properties and water flow velocities are not abnormally large."

In conclusion, present predictions about the Chariot Project are summarized. The simultaneous detonation of four 20-KT devices at a depth of 400 feet and one 200-KT device at 700 feet is expected to make an excavation about 3/4 of a mile long, 1/7 to 1/3 of a mile wide and, a minimum of 30 feet deep. Five percent of the radioactivity produced is expected to escape. Isotopes with gaseous precursors such as Sr^{90} and Cs^{137} will predominate. Upon reaching the surface some radioactivity should adhere to large particles that have been thrown into the air and fall out relatively close to the site of detonation. There would be little or no contamination of the ground water unless tritium were present. The radioisotopes present in the insoluble, fused material and on the crushed rocks would be the usual fission products plus the induced radioisotopes produced from the materials and rocks surrounding the device.

In order to determine the "biological cost" of the Chariot Project a full-scale ecological program has been initiated under the direction of Dr. J. N. Wolfe, Division of Biology and Medicine, U. S. Atomic Energy Commission. There are 23 parts to the program and it probably represents the greatest concentration of effort at any place or any time on an ecological problem. After two years of work on the program it would now be possible to compare conditions "before" the event with what they might be "after" the event, in case approval is granted for completion of the Chariot Project.

DISCUSSION

Q: How long after the detonation will they be able to move in with ships and use the harbor?

A: You can go in the first day, if you want to stay a short period; the second day, a longer period. For commercial purposes I believe a week or two weeks would be perfectly safe.

Q: Do you have any ideas regarding the effect of the tremendous heat on the permafrost, especially as it may affect the construction of docks and piers and other facilities?

A: We have soil people who are studying the various aspects of the soil movement and the effect of heat. The people at Ohio State Agriculture Station have the major responsibility in that area. We do not expect any difficulties with foundations for structures.

APPLICATION OF RADIOACTIVE TRACERS IN HYDROLOGIC STUDIES

W. J. Kaufman*

Radioactive tracers afford the hydraulic and sanitary engineer a potentially valuable tool for the investigation of a wide variety of natural phenomena involving the movement of water, the transport of sediment, and the dispersion of waste materials in the hydrosphere. As is often the case with a new tool, a period of trial is required to establish both the areas where application may be advantageous and situations where disadvantages preclude beneficial use. Prejudice has worked both for and against the full development of radioactive tracer methodologies. Early scientific experiences, often overly publicized in the popular and scientific press, led many to the impression that here was the panacea to all problems. As a consequence, great expectations were held, only to be shattered as the attempts to reach solutions with tracers progressed to their partially successful conclusions. Three of the greatest obstacles have been cost, technical complexity, and apprehension regarding the health and safety problem. As the regulatory aspects of radiation control leave the Atomic Energy Commission's jurisdiction and become shared and dispersed among a host of state and local agencies, we may expect the additional obstacle of red-tape frustration to enter the scene.

In what ways may tracer applications lead to a better understanding of hydrologic phenomena? By labeling a mass of water or silt, without modifying its physical or chemical properties, it becomes possible to directly observe its movement in both space and time and, in effect, to distinguish one otherwise identical unit of the labeled material from all other material. The mixing or dispersing reactions occurring in natural surface or ground water bodies are often too complex to be amenable to analytic formulation, and the construction of physical or analog models may not be economically or technically feasible. However, by the application of tracers we may directly observe the phenomenon of interest in the full scale system. In conducting such studies it is often possible to employ natural tracers, such as the differences in

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chlorinity or the presence of a particular chemical constituent, or to use added chemicals or dyes, with little special advantage accruing from the application of a radionuclide. In such instances, only a full knowledge of the problem can lead to the most suitable tracer selection. It should be emphasized that the application of tracers, either radioactive or stable, generally does not simplify the problem analysis, but rather requires a far more sophisticated appreciation of pertinent physical and chemical relationships.

Criteria in Tracer Selection

The selection of the most suitable tracer for a particular investigation entails the consideration of a great many factors. These factors have been listed in three categories:

1. Physical and Chemical Integrity. The tracer selected should faithfully follow the medium it has been employed to trace, without influencing the movement in any way. For example, the introduction of several hundred pounds of sodium chloride into a well to follow underground water movements may create density gradients completely distorting the phenomenon under study. On the other hand, many of the radionuclides, though of such negligible mass they will not influence the passage of water through a porous stratum, may undergo chromatographic separation on natural ion exchangers and move at velocities far less than that of water. Certain chemical tracers, nitrate for example, may undergo decomposition and pass undetected by the chemical test intended for their measurement.

2. Acceptable Hazard. It must be admitted that the radioactive tracer will represent a greater risk to the investigator and the public than will most chemical tracers. It must also be accepted that current research strongly supports the thesis that even very small radiation exposures are not beneficial and very probably harmful, though to a small and unmeasurable degree. Where the application could conceivably incur some small exposure to the public at large, the investigator may be required to justify this exposure in terms of the benefits expected to accrue from his investigation. Such a justification may find little concensus at a public hearing and the pressure of adverse public relations may often deter management from employing radioactive tracers in offsite studies.

3. Cost of a Tracer and Its Measurement. The cost of a tracer, be it radioactive or stable, cannot be separated from the effort, both technical and monetary, to quantitatively determine its presence. A costly tracer may be quite satisfactory, providing it can be readily measured at extremely low concentrations with relatively inexpensive instrumentation and a low cost per analysis. Continuous measurements in situ are often desirable and less costly than sampling combined with laboratory determinations. Such measurements are feasible with gamma emitting radioisotopes and commercial equipment; but not so with such sensitive chemical tracers as fluorescein or spent sulfite liquor solids (Orzan). A comparison of two of the more satisfactory chemical tracers and tritium was made by Pearson (1) and is given in Table 1. It is interesting to note that the cost of tritium expressed on a weight basis is nearly 10 million dollars per pound, yet the cost of tritium required to label a million cubic feet of water is only 10 cents, less than that for either of the chemical tracers.

TABLE 1

COMPARISON OF TRACER CHARACTERISTICS*

Tracer	Minimum Detectability	Amount Reqd. for Tagging 10^6 ft^3	Tracer Cost 10^6ft^3 $	Analysis	
				Method	Man-Hr/ Sample
Tritium	10^{-6}µc/ml	28 mc	0.10	Liquid Scintillation Counter	0.15
Orzan	0.1 ppm	6.24 lbs	0.30	Spectrophotometer	0.10
Fluorescein	0.04 ppm	2.50 lbs	14.40	Spectrophotometer	0.10

*After Pearson (1)

A few examples of specific tracing situations will serve to further our understanding of selection criteria. The problem of tracing water through the earth, particularly through strata containing clays or organic matter, places a very severe restriction on the list of completely satisfactory tracers. All of the cationic tracers, including the radioisotopes, would be unsatisfactory due to the high degree of sorptive loss that must be expected. Furthermore, almost all

elements or compounds exhibiting any significant polarity, either positive or negative, and introduced in small concentrations, are likely to experience some adsorption which may delay and modify the tracer arrival pattern at a distant observation point. For example, radioiodine introduced as the iodide ion is readily adsorbed by natural soils and thus will not correctly depict the passage of water. The addition of carrier iodide, i.e., iodine in the form of the stable salt, will reduce the degree of sorptive loss, but also increase the investigation costs. Where waters naturally containing iodine are employed, as might be the case in well-field brines, the carrier addition may be unnecessary since many brines contain appreciable concentrations of the iodide ion. Of all the currently available radioisotopes, tritium (hydrogen-3), in the form of tritiated water, appears to most closely meet all criteria as the ideal ground water tracer. However, one can conceive of situations, flow through limestone solution channels for example, where fluorescein or other dyes may be quite satisfactory, since the adsorption limitation would probably be absent.

If various potential tracers were being examined as labels for clay sediments, the chemical criterium regarding adsorption would, of course, be almost diametrically opposite to that for water tracers. Krone (2) has shown gold-198 and scandium-46 to be almost permanently fixed to the sediments of San Francisco Bay, even after prolonged contact with sea water. Ellis (3) has reported quite similar results in studies in the Sidney Harbor, Australia. Paradoxically, Hull and Macomber (4) have successfully employed radiogold as a water tracer for stream gauging with relatively little sorption loss. In the presence of suspended material in the course of deposition by a change in stream regimen, gold would probably prove unsatisfactory as a water tracer and perhaps tritium would be the only entirely satisfactory isotope.

The Problem of Measurement

Probably all radioisotopes conceivably suitable for hydrologic investigations will emit either beta radiation or beta and gamma radiation simultaneously. Since beta radiation, even the more energetic radiation from such radioisotopes as yttrium-90, has a range in water of no more than one centimeter, a beta detector placed in a water labeled with a beta emitter will "see" only a very small volume. To some extent, this disadvantage of the beta emitter may be overcome by evaporating a large sample of water and analyzing the dried radioactive

residue in an internal proportional detector especially designed for this purpose. This procedure has the disadvantage of requiring greater laboratory technician time.

On the other hand, the employment of a gamma emitting radioisotope and a gamma sensitive detector permits the in situ measurement of a relatively large sample, since the tenth value thickness of water*, including build-up, for a one Mev gamma source is in the order of 100 cm. These various aspects of the sensitivity of a radiation measurement system may be expressed in terms of a "Minimum Detectable Activity Concentration" (5) as defined by equation (1)

$$\text{M.D.A.C. } (\mu c/ml) = \frac{9.0 \times 10^{-5}}{E v} \sqrt{\frac{n_b}{t}} \quad \ldots\ldots\ldots (1)$$

in which E is the detection efficiency as a per cent, v is the volume of the observed sample in milliliter, n_b is the instrument background in cpm, and t is the interval of measurement in minutes. A concentration of radioactive material as defined by equation (1) would equal that just detectable at a 95 per cent confidence level.

Several tracers and their respective measurement systems are compared in Table 2 in terms of M.D.A.C. and the counting rate observed per unit of radioisotope concentration. The data are not strictly comparable since the counting geometries are not identical for all measurements. The tritium data are based on a laboratory measurement of a 32 ml water sample. The remaining values are based on measurements with sensitive probes placed in various containers, including containers sufficiently large to comprise an "infinite volume". By way of comparison, if an internal proportional detector were used to measure cesium-134, it would be necessary to evaporate approximately 15,000 ml of water to achieve a 10 minute counting sensitivity corresponding to an M.D.A.C. of 0.016 $\mu\mu c/ml$. Such an observation would depend on the measurement of the beta radiation of the dried cesium-134 deposit. Thus, it is amply evident that from a sensitivity of measurement standpoint, tritium is the least satisfactory of the tracers listed and that gamma emitting radioisotopes have a very appreciable ad-

*The thickness of water required to attenuate gamma dose rate by 90 per cent.

vantage over beta emitters. Furthermore, the in situ measurement of gamma radiation has a special advantage in studies of dispersion in lake and estuarine waters where a moving probe may feed into a ratemeter and strip-chart recorder for continuous radioactivity measurements. However, under these circumstances, the M.D.A.C. values in Table 2 are overly optimistic and should probably be increased by a factor of 10. As noted earlier, an overriding consideration must, of course, be the physical and chemical integrity of the tracer, a criterion that may lead to the selection of some "less detectable" isotope.

Health and Safety Considerations

The hazard to the public of a water tracer is most often judged in terms of the Maximum Permissible Concentration in drinking water, since the domestic water supply would represent the most likely avenue of exposure associated with a tracer study. It is conceivable that under some circumstance absorption of the tracer by edible fish might lead to significant human exposure; but the likelihood of this occurring appears most remote. Similarly, the adsorption on mud on which humans might subsequently walk appears equally improbable. The isotopes listed in Table 2 are shown in Table 3, together with their half-lives, characteristic radiations, current M.P.C. values, the latter reported by the A.E.C. in January 1960(7). In the last column of Table 3, the ratio of M.P.C. to minimum reported M.D.A.C. has been tabulated to indicate a "relative factor of safety" at comparable experimental accuracy. One of the advantages of tritium becomes apparent, i.e., its low hazard, and tritium, gold, and bromine are seen to have nearly comparable capabilities if compared on the basis of equivalent hazard and detection sensitivity.

Table 2 -- see following page.

TABLE 2

COMPARISON OF MEASUREMENT SYSTEMS FOR VARIOUS RADIOISOTOPES

Isotope	Measurement System	$\frac{cpm}{\mu c/ft.^3}$	Background cpm	M.D.A.C., μμc/ml	
				t = 0.5 min.	t = 10 min.
Hydrogen-3	Liquid Scintillation Spectrometer. 32 ml HTO Sample	146	43	4.5	1.0
Iodine-131	5 G.M. tubes in 12 in. wide x 7 in. deep channel	368	680	7.2	1.6
Iodine-131	2 in. dia. NaI crystal in 12 in. x 7 in. channel	4,540	4,470*	1.5	0.33
Gold-198	2 in. dia. NaI crystal in. 3 ft. dia. x 2 ft. deep container. Spectrometer used	5,300	50	0.13	0.030
Gold-198 (Hull, (4)	4 G.M. tubes in infinite vol. water	7,400	170	0.17	0.039
Bromine-82 (after Ljunggren (6)	1.5 in. dia. NaI crystal in infinite vol. water	17,700	50	0.040	0.009
Cesium-134 (4)	4 G.M. tubes in infinite vol. water	18,400	170	0.072	0.016

*Discrimination inadequate, noise could be reduced.

TABLE 3

CHARACTERISTICS OF RADIOISOTOPES EMPLOYED AS WATER TRACERS

Isotope	Half-life	Radiation Energies, Mev		M.P.C.* Water μμc/ml	M.P.C. / MDAC
		Beta	Gamma		
Hydrogen-3	12.46 yr	0.018	None	3,000	3,000
Iodine-131	8.14 d	0.608 (87.2%) 0.335 (9.3%) 0.250 (2.8%)	0.364	3	10
Gold-198	2.69 d	0.963	0.412	50	1,700
Bromine-82	35.9 hr	0.465	0.547 to 1.312	40	4,500
Cesium-134	2.3 yr	0.648 (75%)	0.561 to 0.794	9	560

*Ref. (7), Appendix B, Table 2

The longer half-life of tritium can prove of both advantage and disadvantage, depending on the circumstances of application.

An example may serve to illustrate an approach to estimating the biological risk of conducting tracer studies. It has been proposed that a tracer study be conducted of the ground water artificially recharged into the San Gabriel Valley of southern California. Various objectives of the study include that of identifying the beneficiaries of the recharge program and determining the fraction of the water recovered. (8) Since the investigation involved long-term underground tracing, tritium was selected as the only suitable radioisotope. It was proposed that 500 curies of tritium be diluted in a flow of 40 cfs over a period of 35 days, so as to uniformly label 825 million gallons of water with a tritium concentration of 160 μμc/ml, about 5 per cent of the lifetime M.P.C. (Table 3).

Accepting the value of 10 days of life-span shortening per roentgen exposure, and making additional assumptions regarding water use, one finds the total biological "risk" to the present population is about 2,500 man days. In an affected population of 100,000 persons, the individual risk would be about 0.6 hours.

By similar, but more tenuous computation, the total genetic risk may be estimated at 5,900 man-days for a total biological "risk" of 8400 man-days. These are average values, but since the maximum risk to any individual was estimated to be about 4 hours, the average values are a reasonable basis of analysis. What normal activity of man incurs a risk comparable to 0.6 hours? Jones (9) has computed the life shortening effects associated with the normal characteristics and habits of man. As typical of these, city versus country dwelling results in 5 years of life-span shortening, a package of cigarettes per day exacts a cost of 9 years, and the motor vehicle costs the average passenger 0.67 years. It appears that 0.6 hours is an extremely modest risk.

In examining the risks of a venture, it is only fair to consider and perhaps even equate the benefits. In the case of the San Gabriel study, the benefits are difficult to quantitate since the primary objective was improved water management. However, since the value of water introduced into the earth by the various recharge operations is expected to reach three million dollars per year, the knowledge gained from the tracer study could conceivably benefit the public to the extent of several million dollars over a 20-year period.

Although the above computations are technically sound, their acceptance by the man on the street and his political representative will require a far more emotion-free understanding of radiation than now exists. In spite of the "unpopularity" of the benefit-risk approach to appraising biological damage from low-level radiation exposure, it is considered to be the only adequate philosophy enabling us to live with radiation and make it pay.

A Tracer Application in Waste Disposal Operations

A study has been underway at the Sanitary Engineering Research Laboratory of the University of California with the objective of developing design criteria for injection disposal systems for low and intermediate level radioactive wastes. The ultimate purpose of this investigation is to make possible the permanent storage of such wastes in connate water bearing formations, perhaps at depths of 6,000 to 10,000 feet. Pilot scale studies have been completed on a shallow confined aquifer and a simple two-well system, one well serving as the injection well and the second as a relief well. A layout of the well field system is shown in Figure 1.

The immediate concern of the study has been to estimate the time of travel of the radiocontaminant strontium-90 from the injection to the relief well and to compute the useful waste storage capacity of the formation. The general approach has been to employ tritium to trace the movement of water between wells, and to ascertain the distribution of velocities of flow. Core samples from the receiving formation have been studied in the laboratory to determine the ion exchange properties and to permit the computation of the relative velocities of water and strontium-90. On the basis of the measured water velocity distribution in the formation and the relative velocity of tritium to strontium, it becomes possible to predict, within acceptable limits of error, the time of arrival of strontium-90 at the relief well.

The partial results of one field investigation of the two-well injection system are shown in Figure 2. Although it appears that some small amounts of strontium-90 arrived at the relief well (100S) in about 80 days, this is probably due only to statistical variation in measurement. One hundred and fifty days of operation were required for the first trace of strontium to appear at the 100S well.

The use of water tracers appears to be the only satisfactory means of ascertaining the flow and dispersion characteristics of underground formations and such methods are finding wide application in the petroleum production industry. Of the isotopes listed in Table 2, only tritium is satisfactory for such purposes.

Figures 1 and 2 appear on next page.

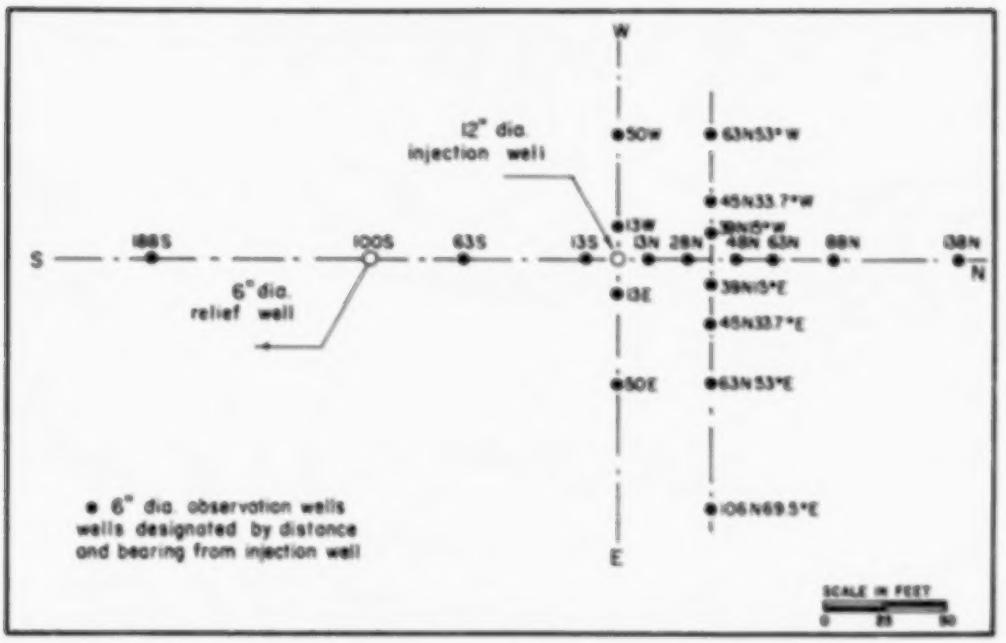

FIG. 1 LAYOUT OF TWO-WELL INJECTION SYSTEM

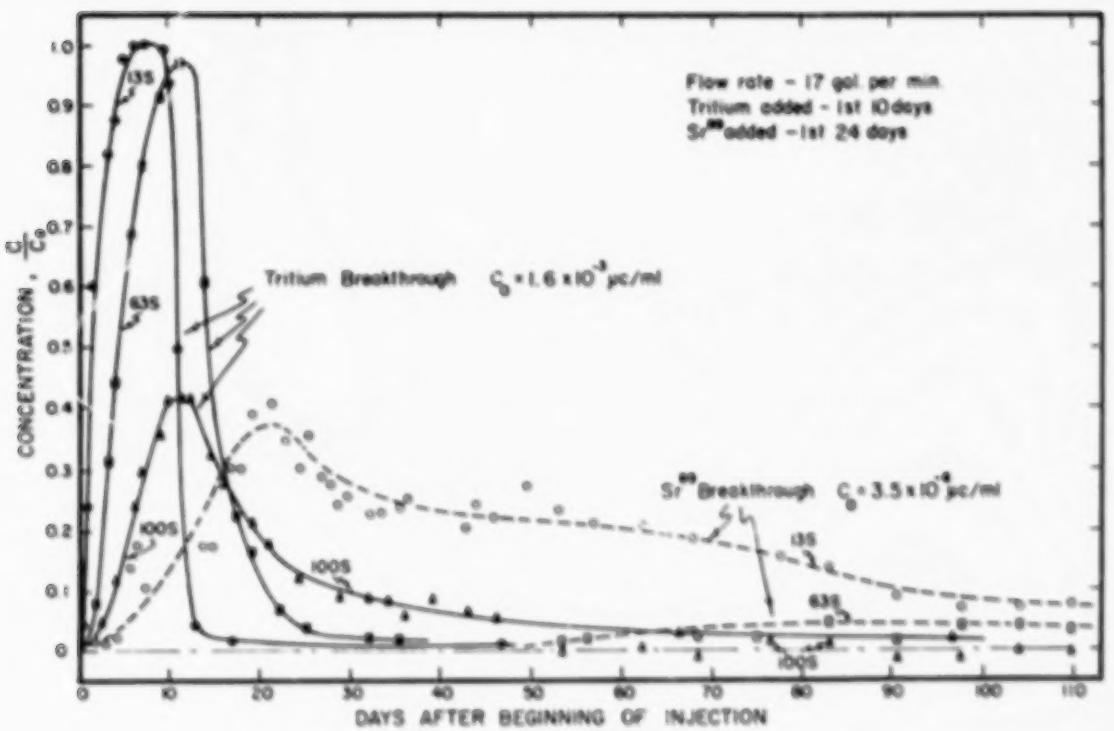

FIG. 2 TWO-WELL INJECTION STUDY

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RADIOISOTOPES FOR FLOW MEASUREMENTS

B. A. Fries*

INTRODUCTORY REMARKS

This symposium up to the end has regarded radioactivity as a pollutant, now Professor Kaufman and I are here to suggest its deliberate addition to water streams for useful purposes. Professor Kaufman has ably defended the thesis that the radiological hazard is a slight one. Our own experience on the dispersion of large amounts of tracers, added to measure river flow, completely supports this view.

Radiotracers are now widely used for water problems; not only to measure flow rates, but to study flow characteristics - flow patterns, dispersion, and retention times - in large bodies of water, and to measure siltation by radiotraced particles.

In the field of flow measurements, a radioactive method, the total-count method, has been applied successfully to measure flows in pipes and in open conduits, such as ditches and rivers. The procedure and its application to river flows will be discussed here.

PREPARED REMARKS

Approximate flow methods have been developed for open conduits, but these require either obstructions to the flow, as by weirs or flumes, or extensive velocity traverses of the channel with a current meter. The dilution method, a well-known alternate procedure using tracers, does not have the above limitations. A solution of a chemical or radioactive tracer is added to the stream at the constant rate, q and concentration, C_q. By measuring the concentration downstream C_q, the total flow Q can be computed. Thus,

$$Q = \frac{C_q}{C_Q} \times q, \text{ where } q < < Q.$$

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This procedures has its own limitations, besides the obvious mechanical ones. Thus, the samples must be taken, usually for later laboratory analysis, often enough and long enough to insure that the final steady state concentration has been reached.

Total-Count Method

A new radioactive procedure, the total-count method, transcends most of the difficulties of the older methods. It shares with the dilution method the following features:

1. It works in any size or shape of conduit.

2. There is no pressure drop, loss of hydraulic head, or obstruction of flow.

It differs in the following ways:

1. The tracer is added all at once or irregularly, if necessary, rather than uniformly over a long period of time.

2. Measurements are made in the stream as the transient tracer wave goes by.

The principle is the following: A known quantity of tracer A is added to the stream. A detector, for example, a Geiger counter, is placed in the stream at some downstream point. While the tracer passes, pulses from the counter are accumulated on the counting scaler. After all the tracer has passed, the total number of counts, N, corrected for background is recorded.

The value of N is inversely proportional to the flow rate Q, since a slow-moving stream allows more time for counts to accumulate. N is directly proportional to A; the more tracer, the more counts. Therefore,

$$N = AQ/F \quad \text{or} \quad Q = AF/N.$$

The proportionality constant F is characteristic of the isotope and of the counter and its geometrical relationship to the stream. The dimensions of F are related to those of A and Q. Thus,

$$Q \text{ gal/min} = \frac{A}{N} \frac{\text{microcuries}}{\text{counts}} \; (\text{or c}) \times F \; \frac{\text{counts}}{\text{c}} \times \frac{\text{gal}}{\text{min}}$$

The value of F can be determined in the laboratory by a static measurement. A counter is exposed to a tracer solution in the same geometrical fashion as in the field, and the counting rate from a known concentration of tracer is measured. Thus, by rearrangement,

$$F = \frac{\text{counts}}{\text{min}} \Big/ \frac{\mu\text{c}}{\text{gal}} = \frac{\text{counts}}{\mu\text{c}} \times \frac{\text{gal}}{\text{min}}$$

The divided-stream principle makes the method applicable to mreasurement of open streams. Supose the tracered stream is split into two branches, say of equal size, but unequal flow. The counter is placed downstream below the wye. Now, the fraction of the flow measured is xQ; but because the tracer was uniformly mixed above the wye, the fraction of the tracer passing the counter is xA. Then the number of counts is

$$N = \frac{xA}{xQ} \cdot F = \frac{AF}{Q}$$

Hence, the same number of counts is obtained as on the whole stream; and it is not necessary to know the value of x.

This makes it possible to gage a large stream by measuring only a small part of it and, in particular, to measure open streams. Consider the stream divided by imaginary partitions into a number of channels, the size of each channel corresponding to the effective gamma-ray range of the tracer. Tracer flowing in more distant channels does not affect the counter because the exponential absorption of gamma rays in water limits their penetration to a few feet, and the inverse square law rapidly diminishes the effective geometry of the counter.

The channel selected for counting may carry a current faster or slower than the average of the stream, but the same total count is obtained in this channel as in any other. In fact, if the whole stream could be forced into this one channel, the same N would be obtained.

Application

The total-count method has been applied to the measurement of open streams of waste water in petroleum refineries and

to the flow of several modest-size rivers, principally the American River above Folsom Dam, California.

The counter consists of a bundle of four 1 x 12-inch Geiger tubes in a waterproof container connected to a portable battery-operated scaler. The tracers used have been 2.3-year cesium-134 and 2.7-day gold-198. For flows as large as 1000 ft^3/sec, up to 1 curie of tracer is required; but this costs only $60 in the case of gold-198.

The tracer supply is transported in a shielded contained up the nearest point of approach to the river, then sampled and measured at this point. It is then transported, unshielded, on the end of a long carrying pole until it is dumped into the river.

The results of many tests showed excellent agreement with a well-calibrated current meter. The convenience of the measurement can be measured by the time required to complete a test. The accuracy depends critically upon thorough mixing of the tracer in the stream and upon its persistence in the stream. Some results illustrating these criteria are given below.

Test Duration

In Table I the time required for the first appearance of the tracer after its addition and the time required for the tracer wave to pass are shown.

Table I

Time of Passage, Minutes

South Fork, American River, Flow 1000 ft^3/sec
Gold-198 Tracer

Test No.	Distance, Ft.	First Appearance	Tracer Wave
1958-1	2500	8	45
	5000	36	59
1958-2	10,000	-	125
1958-3	20,000	60	280

In addition to these times, some time is also required for a preliminary background count to complete a test. Actually, the total time of passage does not vary much with the size of the stream. A test on a natural stream 100 times smaller than the above took about as long.

Mixing

The extent of mixing was determined by comparing the total count measured on opposite sides of the stream. The results of several tests are shown in Table II.

Table II

Extent of Mixing

American River, Flow 1000 ft^3/sec
Gold-198 Tracer

Test No.	Branch	Distance, Ft	Course	Mixing, %
1957-1	North	750	Straight	93
1957-2	North	750	Straight	90
1957-3	North	2500	Straight	99
1957-4	Middle	1200	4 turns	99
1957-5	Lower North	1300	2 turns	99
1957-6	South	1200	Straight	90
1958-1	South	2500	Straight	99
1958-2	South	5000	Straight	99

The results show that it is not difficult to attain complete mixing in turbulent streams within relatively short distances. Mixing was complete in 1/4 - 1/2 mile, depending upon the configuration of the river.

Persistence

The loss of tracer through precipitation or adsorption on the soil or on algae in the stream bed was measured by comparing the total count recorded on several counters distributed along the river. In 1958, Test 1 and 2 (Table I), 3 counters at distances of 1/2, 1, and 2 miles showed the same total count within $\pm$ 2%. The dropout was thus less than 3% in 2 miles. In

Test 3, the dropout was 8% at 4 miles, based on an upstream reading. Part of this was caused by incremental flows from tributary streams. Hence, a reasonable upper limit of the loss is 2% per mile.

The range of distances over which satisfactory measurements can be made are determined as follows:

1. The lower limit is set by the requirement of complete mixing.

2. The upper limit is set by the loss of tracer.

3. A practical upper limit, in the absence of any loss of tracer, is set when the dispersion of tracer along the stream becomes so great that the net counting rate is small compared to background or when too much time is required to observe the passage of the tracer wave.

In tests described here, the practical upper limit was about 2 miles.

Radiological Safety

The rapid longitudinal dispersion in the stream quickly reduces a concentrated solution of tracer to tolerance levels for drinking water. From the practical view, there is a useful upper limit to the tracer concentration set by counting conditions. Geiger counters become inaccurate at rates above 100 counts/sec. With the bundle of 4 tubes we use, this rate is attained at a concentration of 2×10^{-4} c/cc for gold-198; the tolerance level for continuous use in drinking water is currently 3×10^{-4} μc/cc.* In the tests described, the peak count rate was much less than 100 counts/sec. Dilution to tolerance levels was achieved within several minutes after the addition of tracer.

External gamma-ray exposure to a swimmer in the water was negligibly low, about 0.0025 mr per test. The only precaution taken was to exclude swimmers between the tracering point and the counting station during the tests.

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* Effective January 1, 1961, this concentration will be reduced to 5×10^{-5} μc/cc (Title 10, Atomic Energy; Part 20, Standards for Protection Against Radiation, Paragraph 20.106). However, for the purposes of this regulation, concentrations may be averaged over a period of one year. Hence, this change in no way restricts the tracer application.

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3. D. E. Hull, 3rd Industrial Nuclear Technology Conference, September 22-24, 1959, Chicago.

4. U. S. Patents, 2,826,699 and 2,826,700, D. E. Hull, assigned to California Research Corporation.

DISCUSSION

Q: What is the method for computing the flow?

A: We are using the formula $Q = \frac{AF}{N}$. A is the millicuries added. N is the total number of counts. For instance, in the American River we added 1,000 millicuries and had a count of 10,000 (actually, the count may have been 11,000, but it was necessary to subtract the background of 1,000). F is the count of millicuries per gallon per minute. All you do is add the isotopes and count the number of radiations. F is determined in the laboratory.

Q: What brand of tube is used?

A: It doesn't make any difference.

Q: How about aging?

A: We have used our tubes a long time and they have presented no problem. They cost about $15.00.

Q: Couldn't this be done by collecting samples from the stream, compositing them and then running the analysis for radioactivity in the laboratory?

A: Yes, but you wouldn't know when to start and when to stop taking samples. This might entail the collection of a larger number of samples than are necessary. By running the analysis in the field, we know exactly when to start and when to stop by the counts obtained.

Q: In certain situations where it would be undesirable to use radioactive tracers, could you use nonradioactive tracers?

A: Yes, you could use some colored dyes for instance, and compare the density of color. While this is possible and may avoid the need for obtaining approval for their use, it isn't as convenient as the isotope method. Actually, the scaler used with the isotope

is a totalizer. It adds up and totalizes the flow. This method was used very successfully in Seattle a few years ago as a means of measuring flows in sewers. They set up depth-recording instruments in a number of major trunk sewers, and used this method for determining the rate of flow under various depths of sewage in the trunks.

Wiers and such other types of measuring devices become clogged and require constant cleaning. This is not a problem with the isotope method.

Q: How would you get the value of F for a 36" sewer flowing partly full?

A: This cannot be done directly in the sewer. The sewage is pumped into a standard counting bucket. This is our divided-stream principal. F varies with the Geiger counter you use. This is the principal that they used in Seattle.

Q: Can this same method be used with a large stream?

A: It could. We found it easier to put the tubes in the water.

Q: Isn't the value of F somewhat related to the size of the stream?

A: No. Only to the counter and the tracer. It is important to place the tubes in a position some distance from the shore and submerged about a foot under the surface.

ATTENDANCE AT THE EIGHTH SYMPOSIUM

November 15, 1960

James L. Agee	U. S. Public Health Service	Portland
E. Jerry Allen	Seattle Water Department	Seattle
H. R. Amberg	Crown Zellerbach Corp.	Camas
Joseph T. Barnaby	U. S. Fish & Wildlife	Portland
George D. Barr	Oregon State Board of Health	Portland
A. F. Bartsch	U. S. Public Health Service	Cincinnati
Fred J. Burgess	Oregon State College	Corvallis
John V. Byrne	Oregon State College	Corvallis
Richard J. Callaway	U. S. Public Health Service	Portland
Glen D. Carter	Oregon State Sanitary Authority	Portland
George D. Chadwick	U. S. Public Health Service	Corvallis
D. Chakravarti	University of Washington	Seattle
David B. Charlton	Charlton Laboratories	Portland
J. F. Cormack	Crown Zellerbach Corp.	Camas
John Courchene	Seattle Water Department	Seattle
Gilbert H. Dunstan	Washington State University	Pullman
Leonard B. Dworsky	U. S. Public Health Service	Portland
Edward F. Eldridge	U. S. Public Health Service	Portland
Ken Englund	Atomic Energy Commission	Richland
Richard F. Foster	General Electric Co.	Richland
B. A. Fries	California Research Corp.	Richmond
John Girard	Washington State Dept. of Health	Seattle
Pete Hildebrandt	Washington State Dept. of Health	Seattle
Allan Hirsch	U. S. Public Health Service	Portland
G. LaMar Hubbs	U. S. Public Health Service	Anchorage
Roger James	Washington State Dept. of Health	Spokane
Clyde R. Johnson	Portland State College	Portland
R. L. Junkins	General Electric Co.	Richland
Earl N. Kari	U. S. Public Health Service	Portland
Warren J. Kaufman	University of California	Berkeley
Arthur R. Keene	General Electric Company	Richland
J. G. Knudsen	Oregon State College	Corvallis
L. B. Laird	U. S. Geological Survey	Portland
Milton W. Lammering	U. S. Public Health Service	Cincinnati
Robert E. Leaver	Washington State Dept. of Health	Seattle
Byron E. Lippert	Portland State College	Portland
Alfred Livingston	Washington Pollution Control Comm.	Olympia
Robert J. Madison	U. S. Geological Survey	Portland
Bruce McAlister	Oregon State College	Corvallis
Alfred T. Neale	Washington Pollution Control Comm.	Olympia
R. H. Nussbaum	Portland State College	Portland
Charles Osterberg	Oregon State College	Corvallis

Ralph F. Palumbo	University of Washington	Seattle
Wm. G. Pearcy	Oregon State College	Corvallis
John R. Prince	Oregon State College	Corvallis
Robert L. Rulifson	Oregon Fish Commission	Portland
V. F. Santos	U. S. Geological Survey	Portland
Clyde S. Sayce	Washington Dept. of Fisheries	Seattle
Arthur F. Scott	Reed College	Portland
Allyn Seymour	University of Washington	Seattle
Robert L. Stockman	Washington State Dept. of Health	Seattle
J. D. Stoner	U. S. Geological Survey	Portland
Robert N. Thompson	Oregon Fish Commission	Clackamas
John D. Thorpe	Good Samaritan Hospital	Portland
Ernest C. Tsivoglou	U. S. Public Health Service	Cincinnati
R. A. Wagner	Washington Pollution Control Comm.	Olympia
Michael Waldichuk	Fisheries Research Board of Canada	Nanaimo, B.C.
R. B. Walton	Portland State College	Portland
Jack Weathersbee	Oregon State Board of Health	Portland
R. E. Westley	Washington Dept. of Fisheries	Quilcene
C. F. Whetsler	City Water Department	Pasco, Wn.
John N. Wilson	U. S. Public Health Service	Portland
Paul Zimmer	Bureau of Commercial Fisheries	Portland